

METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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Subscription Rates throughout the World - - 24/- per annum, Post free
Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 21, Albion Street, Manchester, 1.
Telephone: Central 0098. Telegrams: "Kenpred," Manchester.

LONDON OFFICE: Bedford Street, W.C. 2.
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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

MARCH, 1945

VOL. XXXI. No. 185

Economic Liberty

FROM time to time we have stressed the need for the careful planning of industry with a view to the prevention of the kind of chaos experienced in Britain after the last war. Now that our belief in ultimate victory has been transformed into a well-founded conviction, the thoughts of responsible people are being turned more urgently to the problems which peace will undoubtedly bring. It is important that this should be so, for events do not wait upon plans. Indeed, some of these problems are upon us for which adequate plans have not been made and our future prosperity depends upon their rapid solution. Even though we plan to achieve and maintain maximum efficiency in every department of our national life, it must include greatly increased participation in world trade and some degree of world stability is needed to facilitate trade. In this connection high hopes are placed on the provision for an economic and social council in the Dumbarton Oaks proposal. This gives the signatory nations the opportunity to remove economic frictions that generate trouble and ultimately war.

In view of present trends, however, problems are being presented for which adequate provision has not been made, and it is doubtful whether it can be made without much greater sacrifice on the part of the Allied Nations, mainly the United States and the British Commonwealth. It will have been noted that as countries are being liberated difficulties are increasing and it may be that we are in the midst of a world revolution in which the world's people are asserting their demand for a better economic way of life. Mankind is seeking economic liberty, and, as Mr. W. L. Batt, vice-chairman of the U.S. War Production Board stated recently, we must face this challenge realistically and solve it intelligently and effectively. Private enterprise, the profit system, classical economics—none of these could withstand the fury of the drive of the world's people for security and freedom from want.

We have organised a great war machine and we have applied it with effectiveness, but the urgency of that operation has created grave economic consequences for which we have not been able, thus far, to provide adequate answer. In Greece, the trouble was due, in the main, to hunger. We have on our hands an Italy whose economy is desperately disorganised and whose people are despairing and wretched. Similar unhappiness is apparent in other liberated countries and may be expected in those countries soon to be liberated. For instance, only a fraction of what the French need and have asked for has reached France during the last

three months—according to Mr. Batt, about 10 per cent. of what the Germans gave them during a similar period under occupation. It is true, of course, that the Germans did not have to choose, as the Allied Nations have had to, where our limited number of ships could be used to the best advantage. The gravity of the situation in France to-day can hardly be exaggerated. There is food in the country areas, but not in the cities; and while there are good highways re-opened by army engineers, there are pitifully insufficient lorries. During the recent cold months the residents of Paris have had no coal and the official ration, if they could get it, is only 100 lbs. per family a month. Chaotic is a mild word to use in describing the situation.

There has been a tendency to under-estimate the German capacity for economic organisation. It is known now that they turned the continent of Europe into one nation with one money, one transportation system, and virtually one political government. Systems built up during many years were thrust aside. The issue of raw materials, including coal, was carefully controlled by them so as to permit an essential level of production and to compel a certain migration of labour to Germany and to integrate the economy of each section into the broad pattern of the central Reich. It was a job that was done swiftly, doubtless on a previously prepared plan, and with a certain ruthless efficiency which included the corrupting of national morals through "black market" operations. In the territory liberated by the Allied Nations the whole German control fabric has been removed, but no satisfactory organisation has yet replaced it.

Probably the real scourge, however, is not hunger, but unemployment. Half the working force of the Paris area is at present unemployed. In view of the critical manpower situation in both Britain and America it has been suggested that the solution of some production problems may lie in the idle hands and plants of France and Belgium. It is likely that help in this direction will ultimately come, but if the United Nations are determined that Germany shall not regain its economic grasp of Europe, adequate arrangements must be provided, and quickly.

The Allied Nations must be looked upon not only as liberators but as intelligent friends who understand the problems of the countries liberated. The peoples liberated must find a world of ready access for the materials they need and easy exchange for their products with the goods and materials of the rest of the world. This is the sort of world promised by the Atlantic Charter in which Britain and America said, and Russia recently supported at Yalta: "They will endeavour with

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

due respect for their existing obligations to further enjoyment by all states, great or small, victor or vanquished of access on equal terms to the trade and to the raw materials of the world which are needed for their economic prosperity."

After the bitter years of occupation the liberated countries are naturally impatient. While it is particularly recognised that little can be done with the fighting still raging the peoples are now looking beyond the end of the fighting and they wonder if the true condition of their plight is really understood. This is among the problems which offer great opportunities for the economic council of Dumbarton Oaks but as this is not yet ratified, Britain could make a greater effort to alleviate the

distress in these countries until concerted arrangements have been made.

Much larger participation in export and import trade, not only by Britain but by other countries, is vital to a sound world economy, and without a sound world economy peace cannot be maintained when it has been won. Wishful thinking will not assure peace and no political mechanism can provide it, unless it rests on a good economic stability. Britain seeks a healthy international trade, without which there can be no good economic stability, but we can do relatively little while the liberated countries are economically unstable. Let us strive, therefore, to bring about stable conditions in these countries, even though it will, undoubtedly, mean further sacrifices on the part of our people.

Engineering and the British Council

THE British Council was established by H.M. Government in 1934, and a Royal Charter, granted in 1940, defined its purposes as the promotion of a wider knowledge of the United Kingdom and the English language abroad, and the development of closer cultural relations between the United Kingdom and other countries. The Council's funds are mainly derived from a Parliamentary grant, carried on the Foreign Office vote. The Secretary of State for Foreign Affairs is responsible to Parliament for the Council's work in or relating to foreign countries, and the Secretaries of State for the Colonies, Dominion Affairs and India are responsible to Parliament for its work coming within their areas. Since the Foreign Office is the parent Department of State responsible for the Council, a close relationship exists between the Council and the British diplomatic missions overseas. An important field of work is covered by the Science Department, the activities of which include medicine, agriculture and engineering. This Department is advised by the Science Committee under the Chairmanship of Sir Henry Dale, Pres.R.S. The Science Committee comprises several Panels, and the Engineering Panel, with Sir William Larke as chairman, gives advice relating to the work of the Engineering Department.

In endeavouring to promote a better understanding abroad of the status and achievements of British engineering, the activities of this Department are naturally diverse in character. One important field of work is concerned with the practical and academic training of overseas students coming to this country, and in this connection the Department is in touch with the relevant Government Departments, with the Universities and with those local authorities and engineering companies interested in giving practical training. The British Council awards scholarships, mostly post-graduate, to overseas students, on the recommendation of their representatives abroad.

Valuable work has been done in the past by British engineers and scientists serving as Advisers and Professors in overseas Universities and Technical Colleges. The Department helps in making recommendations of suitable candidates for such posts. At present, some fourteen vacancies are being filled in China, Egypt, Iraq, Lebanon, Palestine, Turkey and certain of the Latin-American republics. One method by which the

appreciation of British engineering may be stimulated is by giving advice to those overseas countries who are themselves developing systems of engineering training and education, so that this may be carried out as far as practicable on lines regarded in this country as sound, and with the aid of British equipment. The Council's engineering consultant, who recently visited the Middle East, dealt with this, among other matters, and it is proposed to extend this type of service, which, with the almost universal development of engineering activity, becomes of special importance. It is similarly desirable that responsible Government officials in overseas countries should be invited here to study our systems of training. The question of the supply of equipment from this country is also important, if our methods are to be understood.

The provision of a suitable flow of information concerning British engineering to overseas countries is a matter demanding organisation. This country is fortunate in the quality and variety of its technical publications, whether from the engineering institutions or from the technical press, and the distribution of these overseas should not be left entirely to individual effort. Further, a good deal of translation into foreign languages of this information should be undertaken. This dissemination of technical information involves, in addition to the distribution of periodical publications, the distribution of text-books and of films on technical subjects. To these may also be added the need for special articles illustrating recent progress in British engineering. Such articles are prepared by the Council on a monthly basis and circulated overseas for translation and subsequent publication in foreign technical journals. Engineering booklets, forming part of the "Science in Britain" series, sponsored by the British Council's Publications Department, are published in English, Spanish and Portuguese, and usually comprise short illustrated biographies of eminent British engineers; those of Sir Charles Parsons, James Watt and S. Z. de Ferranti, have already appeared, while others, dealing with Sir Henry Royce, Colonel R. E. Crompton, etc., are in preparation.

The British Council does not render a one-way service; through its representatives abroad, many requests for technical information of all kinds are forwarded to this country. These requests indicate the special interests of engineers in the countries concerned, and dealing with them, directly or indirectly, affords an excellent opportunity of making known the views of British engineers.

The Shape of a Material's Reactions to Force—Part I.

A. C. Vivian, B.A., D.Sc., A.R.S.M.

Since 1940, the writer has been interested in the development of the exiguous basis on which "Strength of Materials" has for so long stood into a foundation more worthy of Engineering and Metallurgy, upon which to build a complete study of reactions to force by every material under all working conditions. His effort has not been quite carried away by the wind of war-time preoccupation, and he has felt encouraged to set forth an account of his campaign for the introduction of a new system of approach to mechanical properties. This should ultimately supply the technologies with data of their media as valuable as that afforded the electrician, for example, by his system of magnetic and electrical properties.

AT one time a good many people thought the earth to be flat and, no doubt, some became so steeped in the notion that difficulty was entailed in escaping from it—difficulty shared, of course, by any attempting to go to their assistance. The campaign of assistance attempted by the writer could be said to involve similar and perhaps even greater difficulties, comparable only with the above if, in pursuing the same analogy, a special supposition is made.

Let it be supposed that, in the past, people had not actually been "flat-earthists," seeing that they had never entertained—far less contemplated—the possibility of the earth having any shape at all! But, for all that, be it supposed that they had arrived at certain limited conclusions about the earth's weather, for example, beyond which they could make no further headway. In order to overcome such a deadlock, clarify the position and point the way to a fuller understanding, it might have become necessary to show that:—

- (a) the earth could and did possess shape.
- (b) the existing ideas were tenable only on the assumption of a flat earth.
- (c) more precise ideas and advancement of knowledge of the weather could only be reached by the more tenable assumption of a round earth.

Major difficulties would be presented if questions of shape were quite neglected in attempts to solve geognostic problems.

As a body, the technicians to whom the new approach to mechanical properties is meant to appeal are hardly aware yet that these properties can be considered as parts of a system, of a scheme of a particular shape; far less have they visualised the shape. On the whole, they have been viewing each property apart, as little more than a "something" obtained from an arbitrary test by calculation with measurements therein made. They resemble the above hypothetical people who tried to fathom weather problems without knowing that the earth had shape. Their superficial views serve immediate and useful ends; but these are limited ends which will lead on to no progress and discovery.

It is, therefore, submitted that if engineers and metallurgists are as vitally concerned with the mechanical properties—the reactions of materials to force—as in fact they are known to be, it must be vital for the future progress of their technologies that they should appreciate the system of relationships existing between the properties, the fundamental shape of the scheme of

which the properties are but closely related individuals. If it be reflected that such technologists might be as heavily handicapped nowadays as electricians would be without their exact system of units related by Ohm's and other laws, then it would seem to be worth while to investigate the possibilities of a much more satisfying basis than that upon which "Strength of Materials" now stands.

The proposed system, like so many others of potential and heuristic value, is simple. Technicians have been plotting stress-strain curves, and perusing stress-strain diagrams for so long, but have yet to see how one suitable stress-strain curve is a complete statement of all mechanical properties of the elementary kind, whilst certain other properties—hardness, fatigue endurance, notch-toughness and damping capacity—are derivatives or compounds of the same. In the electrical analogy—current, voltage resistance, etc., are elemental and are compounded in heating effect, electromagnetic effect, etc.

Four or five obstacles of widely different kinds have hitherto blocked the road to a better understanding, their very diversity accounting for the fact that one or other, or a combination of these difficulties has proved too great in the past for the formulation of any simplification of the whole subject, in spite of the variety of types of mind which must have been brought to bear on on such problems. To describe these difficulties is to explain a good deal.

Conceptions of Properties

Probably the most widely experienced difficulty has been the general impression that the *conceptions* of the properties, such as of elasticity, hardness and toughness, have in themselves a cardinal or elemental value; and that, to be adequate, the tests should provide results in accordance with this implicit belief in the primary significance of certain preconceived ideas and mental pictures. Such a viewpoint has been unfortunate. A quality like hardness may be appreciated and identified through personal reactions sufficiently well for the mental picture, and for the planning of the practical test to elicit (what is described as) "hardness." But, what can be known of hardness as a specific reaction by materials to that particular type of loading? Obviously nothing. Only upon examination of the mechanism of the reaction can hardness as a property of materials be understood at all. On examination, the mechanism of any test may prove surprisingly simple, resembling some familiar mechanism; on the other

hand it may prove to be complex and incomprehensible except through its mathematics. In fact, the original conceptions of the properties, having served their purposes in suggesting types of test, have been outlived. The analyses of these tests have frequently pointed out the inadequacy—sometimes even the inherent falsity—of the very conceptions which gave birth to the tests. The conceptions have been the probes by the use of which considerable advances have been made in understanding the reactions of materials to different kinds of force application; the understanding, or rather the reactions themselves, are the only mechanical properties of any significance for the future; the “probes” may now be forgotten.

Yet, oddly enough, the above difficulty of approach to the matter has not applied in every case. Some of the properties have no traditional background, and minds have remained unbiased, happily fancy-free, towards them. The proof stresses, for example, and fatigue endurance are properties around which minds have weaved no spell; they and some others have always been just what the mechanism of their tests prove them to be. It seems to have been agreed that a material's fatigue endurance cannot bear such resemblance to a man's endurance as to be dismissed as something quite familiar. Examination of this mechanism has revealed much; and “fatigue endurance” conveys nothing to the mind but the revealed mechanism.

Tensile, Compression and Shear Tests

The second obstacle is by no means subtle; it involves no psychological difficulty of approach, and seems to call for a few well-chosen words which shall not mince matters. It might be described as the result of an ingenuous, if not a culpably artless, approach to considerations of stress and strain. The tensile, compressive and shear tests to destruction are carried out by recording the deformation taking place as the load steadily increases, by calculating the stress from the load and area, and the strain from the deformation and length, and by plotting the stress against the strain to obtain stress-strain curves. If stress and strain are deliberately miscalculated for the sake of convenience, or for any of the reasons given in extenuation of such a crime as the “nominal” type of curve, then the curves derived from tensile, compressive and shear tests have very different shapes.

If stresses and strains are calculated properly, however, then the curves for tension, compression and shear are quite similar in shape, and conviction grows that experimental errors and/or purely secondary reasons (of comparative unimportance to the generalisation itself) must be responsible for the small differences between them.

Loading Differences

The third obstacle is a matter of detail; it is the difficulty that there are these small differences between the curves of the three types of loading, even if stresses and strains are calculated properly.

It has been appreciated that the results of the compressive test are incorrect if lubrication is not provided between the ends of the specimen and the jaws of the machine, friction at these points being obviously undesirable and likely to yield erratic results. Sheet lead is sometimes introduced at those points for lubrication. But this is only one recognition of a general truth which

has not been so generally recognised—that, in all these tests which are to be comparable, the lateral strains must be entirely unrestricted. It can be seen that the shapes of these stress-strain curves will be profoundly affected by restriction of lateral strain. In fact, the normal long, low curve of the ductile material may even become the steep, straight line compressibility curve if sufficient restriction of lateral strain is applied. Therefore, no compressive test curve is exactly comparable with a tensile test curve unless its specimen is literally unrestricted in its lateral deformation. Moreover, in the torsional shear test, radial fibre shear is never unrestricted, and only becomes relatively unrestricted in tests on thin tubular sections.

Attention to details, of which the above are only two out of several possible causes of differences in shape, would be found to remove this particular obstacle. Homogeneity and isotropy have to be assumed in any generalisation and these are necessarily lacking in some well-known materials.

Measuring Strain

Obstacle No. 4 is as serious as any. The one true stress-strain curve obtained by the removal of the last two obstacles approaches the shape of the true characteristic curve of the elementary mechanical properties, but suffers from one embarrassing feature. The area underneath the characteristic curve should, undoubtedly, represent the work of reaction by the material per unit of its volume. Unfortunately, the area under the curve obtained up to the present does not; it can be shown experimentally that it does not, and examination of the actual units employed shows that it cannot. The difference between the correct work of reaction per unit volume and that estimated from the usual curve may be as much as 50% or so.

The difficulty here is that the common method of regarding and of measuring strain happens to be unsuitable; it can be overcome quite simply by changing the method, and the commoner conception of strain to one which is not so common and perhaps a little tiresome at first. As usually conceived, strain is $(L-L_0)/L_0$, or deformation be unit of original length; but, as this can only apply properly up to maximum uniform deformation, the complication in the case of a specimen which necks or bulges is adequately looked after by the formula $(A_0-A)/A$ applied to the neck or bulge. The conception of strain is identical in each formula, and it will not satisfy the work reaction requirement of the true characteristic curve.

The type of strain required is that which may be described as “differential” or “logarithmic.” It is the sum total of a vast number of infinitely small changes in deformation each divided by the length actually undergoing deformation. Where ordinary strain is ϵ , or $(A_0-A)/A$, this differential strain is $2.3 \log(1+\epsilon)$, or $2.3 \log(A_0/A)$. This less common kind of strain is simply related to the common kind, and there can be no more objection to making such a change than in changing from a fractional basis to a percentage basis, or from density to specific gravity, or from centigrade to Absolute degrees of temperature. If desired, the usual kind of strain can still be used in measurements of ductility, or for any purpose except that of measuring the specific work reaction of a material. The correct work reaction can be expressed by quite a simple formula in terms of the usual strain; no disturbance is strictly

necessary, though it would be advisable to become accustomed to the idea of this more satisfactory type of strain.

Hardness, Toughness, and Fatigue Endurance

The fifth, and perhaps the final obstacle to the acceptance of one true stress-strain curve to stand for the mechanical properties is the undeniable fact that all the mechanical properties are not exhibited on such a curve. What, then, are hardness, toughness, notch-toughness, and fatigue endurance?

It may have been seen that toughness has just been dealt with; it is, in fact, the specific work of reaction, the reaction by work per unit volume, up to any desired point of stress and strain, up to fracture point if desired. It is similar to proof resilience, the latter being mainly elastic toughness, while plastic toughness carries on beyond the "elastic limit," and a progressively smaller part of it is reversible energy. Toughness is the first compound property, and it can be read direct from the curve employing differential strain.

Turning now to the other properties, which cannot be read direct from the curve, these all appear to be compounded in one way or another from the elements of the true curve. Neither fatigue endurance, notch-toughness or hardness are true "unital" properties, as their figures of merit do not relate to lengths, areas, or volumes in the same unequivocal sense in which all the elementary properties and toughness relate. These should be dealt with separately and at length.

The measure of fatigue endurance is certainly the fatigue "limit" which is a stress. Yet, this stress of the S-N curve is of a hypothetical nature, not directly applicable to the exact localities of failure, but rather to a superficial area of maximum stress at the critical section where failure localities are to be found. At the precise localities of failure, the elemental properties apply honestly enough; but it is only the statistical average effect of the operation of these elements at a number of separated localities that is reflected in this hypothetical "limit." Moreover, failure follows a great number of repetitions of such stress induction, and for this reason alone the latter is as different from the stresses in the standard tests of (single) tension, compression and shear as anything could be.

The measurement of fatigue endurance as a "limiting stress" is a device which serves a very useful purpose; but, like the "ultimate tensile stress," has no reality as a unital property of materials, and should be regarded as nominal. It is not improbable that fatigue endurance will in time be measured in terms of energy and volume as a property compounded from the elements of the curve in some way at present uncertain.

Notch-toughness is measured in foot-pounds of work per specimen tested; yet no attempt is made to estimate the part-volume of the test piece actually becoming involved in the failure. Useful as the Izod and other impact tests are for purposes of comparison, for feeling the way in the dark, no one is to know how much more useful it would be to understand the property sufficiently to have it on a unital basis.

Hardness, measured to-day as a Brinell "number," a stress (or in some manner which proves on examination to be essentially the same) has been subjected to analysis.* It proves to be the axial stress resulting from

reactions from three principal directions at the same time. Hardness stress is a material's axial reaction to any central loading which induces not only an equal and opposite reaction, but lateral reactions as well from two other directions at right angles. Hardness, then, is not the elementary stress of the true curve of the material, but is compounded of elementary stresses.

The theory of such triple stress induction and its application to practical problems has for long been familiar to engineers; the application of the theory to the phenomenon of hardness in explanation of the mechanism of that property is quite recent, however.

Special Tests for Materials

Meanwhile, there are numbers of tests for materials, specimens and special machine parts which have not yielded figures of merit ranking high as standard properties. Attention is drawn to one of the most elementary of these, because light can be thrown on the whole question of the compound properties by examining the following simple case:—

A coiled spring is an example of a special machine part which may be required to undergo a test for, say compressibility. Now, the mechanics of that spring's action is known; let it be supposed that it is, in fact, quite accurately known, and that a perfect stress-strain curve of that material is at hand. In such a case the test itself should be quite unnecessary, because the compressibility of that spring could be calculated with ease.

In the same way, there can be no compound property of which the mechanics, or mechanism, is really understood that cannot be calculated with the aid of the true curve of the material. From such a rule there would be no need to exclude fatigue endurance, hardness and notch-toughness if the mechanisms of the material's reactions to these types of loading were really known. When the above mentioned properties can be calculated, they should give greater satisfaction than they do now; for, by the time they can be calculated, they will undoubtedly be understood.

Toughness, for example, may now be calculated from the stresses (f) and the logarithmic strains (s) by measuring the area under the true curve thus:—

$$\int_{s=0}^{s=s} f \cdot ds$$

and, if the curve shape can be identified by some such formula as $f = k \cdot s^m$, toughness can be calculated without area measurement from:—

$$k \cdot \int_{s=0}^{s=s} s^m \cdot ds \quad \text{which is} \quad \frac{k \cdot s^{(1+m)}}{1+m}$$

This seems to be an exemplary case. If toughness means specific reaction in work per unit volume, and if it is agreed that the area under the true curve measures that property, there can be nothing further to be said about toughness. For, it is a property clearly seen to be compounded from the elements of the true curve in a certain manner. By the criterion of the ability to synthesise a compound property from its elements, toughness is seen to be completely understood.

How about hardness? It is now becoming possible to do rather more than conjecture how hardness may be synthesised if it is viewed in a forthright manner as

* Engineering, June 2nd, 1944. A. C. Vivian—a paper entitled "Fracture: its Energy Distribution and Specific Energy."

strength, elastic and/or plastic axial stress reaction, greater than that of the true curve on account of the lateral strain restriction characteristic of different materials subjected to local or central loading. A recent analysis of the Brinell test shows that, under hardness conditions of lateral strain restriction, the ordinary strength (the stress of the true curve) is increased by the factor $(m-1)/(m-2)$ where m is Poisson's Ratio, or even when it is an apparent Poisson's Ratio in plasticity.[†]

In the case of hardness loading, for any given degree of axial strain induced in the material, indentation strain for example, the corresponding axial stress is $(m-1)/(m-2)$ times as high as that to be expected from the true stress-strain curve. The published values of m apply to what is known as the "elastic range" only, as Poisson's Ratio is supposed to be an elastic property. Any considerable plasticity causes this ratio of the axial strain to the lateral strain to fall to a limiting value of 2 in the fully plastic or liquid state. As m falls, the value of $(m-1)/(m-2)$ rises, and presents a complication into which there is no necessity to go here and now. For, the true curve is also what has been known as the "strain hardening" curve; and, by the time any stress of the plastic range has been induced for a second or two, this strain hardening has so altered the stress-strain characteristics of the material that the comparatively straight part of the curve—the so-called "elastic range"—has risen to this erstwhile plastic stress. The published values of m are applicable once again, since the material's "elastic limit" has risen to the value of the plastic stress sufficiently for their use.

Hence, if a maximum strain (in single loading), a fracture or rupture strain, is induced in compression at the surface of a steel by the indentation of a very hard ball, the "strain hardening"—or (more generally speaking) the strain strengthening—has raised the "elastic limit" of the material to the fracture stress, say, 65 tons sq. in., at least sufficiently for the use (without appreciable error) of the usual value of m , which is 3.3 for the steels. In this case the factor $(m-1)/(m-2)$ becomes 1.77. Therefore, the axial stress required under hardness loading conditions to produce this effect of fracture is 65×1.77 or 115 tons sq. in., or 180 kg. sq. mm., which is the Brinell Hardness Number itself for such a steel, the hardness stress just at the surface where the maximum possible strain (by single axial loading) has been induced.

Similarly, if at some depth below the Brinell ball some strain, such as that of a 25 tons sq. in. "elastic limit" is found to be induced, then the relevant axial stress—to which the Brinell number has degenerated at the depth in question—must be 25×1.77 , or 44 tons sq. in., or 69 kg. sq. mm.

Thus, hardness may be synthesised from the elements of the true curve, and there would appear to be no further necessity to apply tests for it. Alternatively, it could be said, perhaps, that the only point in carrying out a hardness test to-day is that the test, a very simple one in itself, provides a compounding of m and of (single axial loading) fracture stress, neither of which are too well-known to-day, because they do not happen to have been carefully determined. Were the true curve and good values of m both available, there could be no more point in carrying out the hardness test than there is in

carrying out a toughness test on a material for which a true curve is available.

Toughness and hardness have both been demonstrated, then, as examples of compound properties capable of being calculated like the compressibility of a coiled spring. It can be surmised with fair accuracy that fatigue endurance, damping capacity, notch toughness and any of the lesser lights amongst the properties will similarly lend themselves to calculation from the elements of the true curve.

Hitherto, various arguments have suggested that one true stress-strain curve employing a particular conception of strain may stand for all the mechanical properties of materials if it be properly interpreted. This would seem to be correct, and the advantages of such an insight into the fundamental facts can hardly be overestimated, if only because the ground is now clear for further advances in methods of endowing materials with the desired properties of a mechanical nature.

Having reached a definite stage in the understanding of these properties, it is now possible to take further steps in a good direction. It now remains to provide materials with these properties over the whole range of temperatures in which they can be used, and over the whole range of loading rates in which they are likely to be required.

One True Curve

The one true curve to which reference has so frequently been made is the graph obtained on testing at room temperatures and at a rate of loading which involves the fracture of the specimen in a minute or so. Now, the loads, deformations, lengths and areas whose measurements permit the construction of the true stress-strain curve have not unusually been measured with a high degree of accuracy, because the materials tested have lacked the high degree of homogeneity and "repeatability" which would make it worth while to measure accurately. In consequence, comparatively large changes of temperature or rate of applying load in these tests will pass unnoticed in the shape of the stress-strain curve of a material. Yet, literally, the shape of the true curve can only be of fixed shape at exactly one temperature and exactly one rate of applying the load. The shape depends, then, on both temperature and loading rate, or time; and this fact would be perfectly apparent in the testing carried out under slight variations of temperature and time, but for the fact that the measurements made are not careful enough, nor is the available material "repeatable" enough. Whenever such testing is carried out at temperatures and times greatly differing from the normal, differences in the curve shapes become apparent in spite of crude materials and measurements.

In general, the effects of temperature and time on the curve shape is as follows—high temperatures and "high" times (slow loading rate) make the curve shorter and longer, and *vice versa*. There are some complications in the important cases of iron, copper and their alloys. It would seem to be possible to ascertain the shapes of a material's curves at a variety of temperatures and rates of loading, and to express differences in these shapes by means of some kind of coefficient to be applied to a standard curve shape*. This might not be as difficult in practice as it sounds; because it may be found possible to apply a logarithmic formula to the curve

[†] *The Philosophical Magazine* (awaiting publication). A. C. Vivian—a paper entitled, "An Analysis of Hardness."

* "A Renaissance of Mechanical Properties," *J. Mech. E.* A. C. Vivian. Sept. 8 1943 (Received).

shape, and the variation in shape with temperature and time change could then be indicated by changing values of k and of m in such a logarithmic formula as: $-f = k/s^m$.

Even somewhat rough approximations to the mechanical properties at different temperatures and times would be much better than none at all. Up to the present very little attention has been paid to determinations of the curve shape, the graph-base of all the mechanical properties, at temperatures and times greatly differing from those which have come to be considered "normal." Some curves showing how individual properties change with changing temperature are available; and a little work has been done in the direction of discovering the effect of a changing loading rate. The new outlook on the properties suggests that the reasonable thing to do is to provide a standard stress-strain curve with coefficients by which to calculate from it the shape under conditions (abnormal in testing) which may be quite commonplace in forging, rolling, pressing, extruding, drawing, and so on.

Features of the True Curve

The study of curves of certain crystals has suggested the literal reality of an elastic range terminating in a limit of proportionality and/or an elastic limit. However this may be, there is no material of construction in the least like this; in spite of the fact that wrought iron and mild steel superficially appear to be elastic up to points in their curves where a discontinuity occurs and plasticity begins, it is true to say that all materials react to force with a combination of elastic and plastic reaction from the beginning of the curve to the end.

For a few important practical purposes, of course, there may be nothing but usefulness in assuming the truth of Hooke's Law up to some limit of proportionality, and in assuming some elastic limit for a material; in such cases there may be a practical assumption without any literal reality in these limits. But the literal reality asserts itself in no uncertain way when liberties are taken with it, when attempts are made to discover the stage of strain amounting to "mechanical failure." It is then high time to point out that, in reality for materials, there is neither limit of proportionality, nor constant modulus, nor elastic limit, nor point where plasticity commences.

Nor, for that matter can "mechanical failure" be said to take place after a specific amount of work has been done on the material, at some proof resilience. For, "proof resilience" must also disappear with the "elastic limit."

Probably the best course for any disposed to think that there is a very strongly marked "elastic limit" in the case of some materials (such as the steels) is to examine a stress-strain curve of one of the steels, for example, with an extremely open strain-scale. Then, what looks, on the more usual strain-scale as the "straight line" to the "elastic limit" is seen to be a curve, upon which it is well-nigh impossible to place a "limit of proportionality" or an "elastic limit." The more sensitive and accurate the device for measuring the so-called "elastic" deformation of any material, the greater the conviction that there is no literally pure elasticity, and no stress, strain or work at which mechanical "failure" could be said to begin. Nor is there a greater degree of hope in any suggestion that "failure" could be considered to be at the sudden yield of the steels.

In the nominal curve of the tensile test, the highest point reached is quite a notable feature,

and the stress at that point is called the "ultimate tensile stress." On the true curve, however, the stress corresponding to the same strain—of maximum uniform deformation in tension—is not so strikingly situated. Nevertheless, cannot fail to be of rather particular interest, because it is still the stress at maximum uniform deformation in tension, at which (in tension) the rate of strain-strengthening has been overtaken by the rate of reduction of area. But, the true curves of tension, compression and shear are one and the same; so the true value of the "ultimate tensile stress" should also have significance as the stress in compression at which the rate of increase in area overtakes the rate of strain-strengthening. In applied simple shear no such crises would occur, seeing that the simultaneously induced tensile and compressive deformations and strains neutralise one another.

Correspondence

Aluminium Alloy Sheet and Strip

The Editor, METALLURGIA.

Sir,

We have been most interested to read the article on the above-mentioned subject by Dr. E. G. West published in your February issue. We think, however, that the author has been misinformed in regard to the type of rolling mill used for the production of aluminium foil.

In the last paragraph of the section headed "Cold Rolling" it is stated that for pure aluminium foil special mills have been developed "including cluster mills of six or even twelve rolls." The fundamental characteristic of these multi-roll mills is that the working rolls are extremely small in diameter, but whilst it might be thought from theoretical considerations that for such thin metal as foil the roll diameter should be reduced to the minimum possible, there are other more important factors, particularly in regard to the temperature control of the rolls, and it has been found that rolls of relatively large size have proved to be more effective and, moreover, there has been no appreciable practical advantage in using the minimum possible working roll diameter.

As Dr. West may be aware, we have been the pioneers in the design and construction of modern aluminium foil rolling plant and were responsible for the development in this country of mills capable of the high speeds mentioned by him of up to 1,200 f.p.m., and whilst we have obtained very satisfactory results from several mills of the 4-high type with working rolls of relatively small diameter (though not so small as would be indicated by the reference to six or twelve roll mills) latest practice now tends to the use of the 2-high mill which is capable of operating most efficiently at the highest rolling speeds practicable, and are better from the point of view of roll temperature control.

We have noted that the author has referred to the paper by the writer with Dr. Underwood published in "Metal Industry" last year, and he will have seen the description given with illustration of the latest and most efficient type of aluminium foil rolling mill which we are now supplying, the design of which we are confident is in advance of any alternative as yet put forward.—Yours faithfully,

For W. H. A. ROBERTSON & CO., LTD.,
March 10th, 1945. C. E. DANIEL, Director.

The Gravimetric Estimation of Silicon in Aluminium Alloys

By G. H. Osborn and J. Clark

Metallurgical necessities limit the specified silicon content of many aluminium alloys to a very narrow range; quick and accurate methods of analysis are, therefore, essential for foundry control. Very rapid and accurate colorimetric methods are available, but both photometric and spectrographic methods rely on accurate gravimetric methods. Particular attention is directed to the Fuchshuber gravimetric method and causes of failure are discussed; details of a suggested modification of this method are given by which greater accuracy is obtained.

SILICON is always present as impurity in aluminium metal, even in the purest forms ranging from 0.05 to 0.5%, but it is also frequently added in varying amounts as an alloying constituent to definite specifications. Examples of this are the following well-known types: RR 50 or DTD 133B. (2.2-2.8%), RR 56 or DTD 206 (0.6-1.25%), DTD 424 (4-6%), DTD 428 (2-3%), Silumin or L 33 (10-13%). In addition to these and similar alloys, silicon hardeners with upwards of 20% silicon are employed as key alloys. The internal limits of specifications, dictated by metallurgical necessities are often very narrow in range. Quick and accurate methods of analysis are, therefore, essential for foundry control.

Despite the fact that very rapid and accurate colorimetric (photometric) methods^{1, 2} are now available to meet this demand, the need for accurate gravimetric methods is all the more pronounced because it is on gravimetric methods that both photometric and spectrographic methods ultimately rely for calibration and standardisation. Until recently the only gravimetric methods in common use were the Regelsberger,³ the Otis-Handy,⁴ and a very empirical method the so-called "Drowns" method.

The Regelsberger method is based on the conversion of the silicon to sodium silicate followed by acidification and subsequent dehydration of the silicic acid formed; this method is capable of good accuracy, but it is tedious and, owing to the not-negligible solubility of the silicic acid it requires at least two dehydrations to ensure the complete recovery of the silicic acid.

The Otis-Handy is based on attack of the turnings with mixed acid (hydrochloric-nitric-sulphuric) dehydration, boiling in dilute acid, filtering and subsequent fusion of the residue with sodium carbonate whence it follows closely on the Regelsberger method. This method is, in our opinion, also very tedious and slightly less accurate than the Regelsberger.

The "Drowns" method is also based on an acid attack (hydrochloric-nitric-sulphuric), but the residue is not fused with alkali, but burnt off and weighed as a mixture of silicon and silica in a platinum crucible. This residue is then fumed down with hydrofluoric acid to remove the silica and reweighed: from these results the total silicon may be calculated. This method, at the best a compensation of errors, was, nevertheless, widely

used as it was so much quicker than either the Regelsberger or Otis-Handy methods.

In 1939, however, a method was proposed by Fuchshuber⁵ which was entirely novel and which seemed to offer great promise. This method was based upon attack of the turnings with a mixture of phosphoric-nitric-sulphuric acids, which upon evaporation nearly to dryness, converted all the silicon present directly to silicic acid. After boiling with hydrochloric acid, evaporating nearly to dryness, diluting and boiling, the silicic acid could be filtered off, burnt off and weighed as silica.* Thus this method entirely avoided the sodium-silicate stage, required by the other methods, with its inherent tediousness and, in addition, the author claimed that evaporation to dryness was not required and also that all the silicic acid was entirely precipitated, thus cutting out the necessity of the second and sometimes third dehydration required by the Regelsberger and Otis-Handy methods. In view of these claims investigations were carried out in our laboratories over a long period during 1940-41, but it was gradually and reluctantly realised that the method as described by the author would have to be abandoned, owing to several very grave defects. The chief of these were (a) Fuchshuber worked only with high silicon alloys and we subsequently found that the attempt to use his technique for contents less than 6% failed entirely, despite the use of higher weighings (2-5 grams). (b) the silicic acid obtained was frequently found to be gelatinous and almost impossible to filter, (c) the change from yellow to colourless mentioned by Fuchshuber was found to be almost imperceptible and yet of the utmost importance, (d) results very much on the low side were often obtained.

In view of these grave defects attempts to use the method in routine were abandoned, as pressure of work did not permit, at that time, of further experiments. A slightly modified form of the method was, however, used in our laboratories by skilled analysts on high

*For the benefit of those unable to obtain either the original paper or a translation the following is a précis of the essential details. 1 gram turnings attacked with 40 ml. of acid mixture (50% H_2PO_4 , 40% HNO_3 , 10% H_2SO_4). After frothing ceases solution evaporated until conversion of Si to SiO_2 has taken place, cooled and 100ml. water added slowly, followed by 20 ml. hydrochloric acid. This solution is evaporated till colourless and silicic acid comes out of solution. 350 ml. hot water then added and the solution boiled and allowed to stand for 5 minutes before filtering. Filtrate washed free of acid and burnt off to SiO_2 , the purity being checked by volatilization with hydrofluoric acid.

5 Fuchshuber, H. *Zeit. für anal. Chem.*, 1939, **116**, pp. 421-27.

REFERENCES

- 1 Hadly, B. W. *Analyst*, 1941, **66**, 486. 1942, **67**, 5. 1944, 827, 43.
- 2 Stross, W. *Analyst*, 1944, **69**, 815, 44. 45.
- 3 Regelsberger, F. *Zeit. angew. Chem.*, 4, 20, 32, 360-363, 442-6, 473-8 (1891) *J. Soc. Chem. Ind.*, 10, 950 (1891).
- 4 Handy, J. O. *J. Am. Chem. Soc.*, 18, 766-82 (1896).

silicon alloys, e.g., L 33 and DTD 324 with very good success, despite the fact that many routine assistants continually failed to achieve consistent results. Recently, however, the whole method has been re-investigated and the causes of failure demonstrated. Subsequently the method was modified in such a manner that accurate and consistent results are now obtained by routine assistants, not only on high silicon alloys, but also on those alloys where previously the method was found to be quite useless, e.g., DTD 424, RR 50, etc. It has, however, not yet been possible to use this modified technique for the lowest ranges, i.e., 1.5% and lower; the reasons for this are given below.

The Causes of Failure of the Method as described by Fuchshuber

(a) Lack of indicator for the critical range.

Fuchshuber, in his original paper, made no reference to the fact that the method could not be applied to lower silicon contents than about 6%, yet many experienced chemists in various laboratories reported verbally that the method was quit unusable for the lower ranges. One of the reasons for this failure has now been found to be that the point where the solution must be removed during the *second* evaporation is very critical, since prolonged boiling with phosphoric acid, after the removal of the nitric acid, redissolves the precipitated silicic acid, whence it cannot again be recovered. This critical point is, however, extremely difficult to observe since the so-called fading of yellow to colourless is most gradual and indeterminate. The principle of this fading is the decolourisation of the ferric iron by phosphoric acid just as soon as the vast bulk of the nitric acid has been evaporated, but as stated above, this change is very difficult to observe even by experienced operators; if, however, the solution is removed too early, even if only for a minute, it becomes almost impossible to filter the gelatinous silicic acid and, in any case, low results are obtained due to incomplete precipitation of the silicic acid. On the other hand, if the solution is allowed to evaporate too far, erroneous results are also obtained, due to the dissolution of silica in the phosphoric acid, thus giving results once more which are too low. The correct point is, therefore, a very delicate balance between the extremes.

It was, therefore, imperative to find an indicator which would show very clearly the desired point, and after many trials with various salts, e.g., ferric chloride, potassium dichromate, potassium chromate, copper sulphate, manganese sulphate, etc., which proved inadequate, it was found that cobalt nitrate at the requisite concentration gave an excellent colour change from green to blue at the critical point. If the cobalt nitrate is added with the 100 ml. hydrochloric acid the solution is at first slightly pink, but as soon as the water is driven off, and the iron begins to concentrate, the colour is a bright green, due to the yellow of the iron plus the blue of the dehydrated cobalt nitrate. As soon as the phosphoric acid has decolourised the iron, then the solution turns at once to the blue of the cobalt nitrate; in a few alloys this blue is almost a violet, but in any case the change is most distinct. It was found, using standard alloys, that boiling could be continued for two or three minutes, after the colour change, with safety; if the solution were removed before the colour change was complete the silicic acid was very difficult

to filter and, as observed above, low results were obtained, while if prolonged heating were maintained, low results were also obtained. An example of this phenomenon is given below in Table I, in which, however, a different acid mixture was used from that recommended by Fuchshuber.

TABLE I.

1 grm. turnings. 80 ml. acid mixture (30 ml. H_3PO_4 , 40 ml. HNO_3 and 10 ml. H_2SO_4).

Colour during evaporation and time continued.	2.66	5.3	6.18	11.40	20.3	Silicon cont. of standard.
Blue-green	2.59	5.26	6.09	10.97	19.64	Found.
Blue (immediate)	2.61	5.35	6.13	11.23	19.72	"
Blue 2 mins.	2.62	5.33	6.20	11.40	20.22	"
Blue 4 mins.	2.58	5.31	6.27	11.44	19.32	"
Blue 6 mins.	2.46	5.27	6.20	11.25	19.22	"
Blue 8 mins.	2.08	4.75	5.95	11.25	19.04	"

(b) Composition of acid mixture.

Despite the great assistance received from this indicator it was found that by using the acid mixture recommended by Fuchshuber it was impossible to obtain accurate results on alloys containing less than about 6% silicon, the results obtained on the lower ranges being in all cases too low, and with the lowest ranges it was frequently found that no silica at all was obtained. Typical examples of this may be seen in Table II.

TABLE II.

Standard	Silicon found using acid mixture recommended by Fuchshuber.
2.30	1.98, 2.05, 2.02, 1.98
1.00	1.01, 1.00
1.00	Nil
6.18	6.13, 6.15

Experiments were, therefore, carried out on higher weighings, e.g., 2 gram samples for the lower range silicons, but it was found that the solutions evaporated to salts before the conversion was complete, while if still more acid was taken to compensate for the larger weight the excess of phosphoric acid caused very low results. It was, therefore, decided to try altering the composition of the acid mixture, in the sense of lowering the percentage of phosphoric acid and instead of the usual 40 ml. of acid mixture (20ml. H_3PO_4 , 16 ml. HNO_3 , 4 ml. H_2SO_4) recommended we used 20 ml. H_3PO_4 , 48 ml. HNO_3 and 12 ml. H_2SO_4 . This acid failed to clear the solution, but the addition of 20 ml. of the normal acid mixture brought about immediate conversion. To follow this up an acid mixture of 30 ml. H_3PO_4 , 40ml. HNO_3 and 10 ml. H_2SO_4 (all acids concentrated) was used on a 2 gram sample of 2.3% standard and a 1 gram sample of the 11.4 standard. For the first time correct results were obtained on the lower range, as will be seen in Tables I and III, as compared with Table II.

TABLE III.

Acid mixture (30 ml. H_3PO_4 , 40ml. HNO_3 , 10 ml. H_2SO_4).

Colour during evaporation and time continued.	11.4 standard (1 grm. sample).	2.3 standard (2 grm. sample, net 21)
Blue-green	11.28	2.25
Blue (immediate)	11.44	2.35
Blue 2 mins.	11.47	2.27
Blue 4 mins.	11.39	2.05
Blue 6 mins.	11.28	1.27
Blue 8 mins.	7.43	0.57

Other acid mixtures were also tried out, but none was so successful as that given above which has enabled us to extend our range for this method down to 2%

with safety. In the extremely low ranges we have, as yet, been unable to find an acid mixture which will give correct results. We have obtained 0.83 and 0.87 on a 0.96% standard and, therefore, we do not yet feel justified in recommending the method for this low range, i.e., less than 1.5% silicon.

(c) *Prolonged evaporation at the conversion of silicon to silica stage.*

Although not mentioned by Fuchshuber we have found that if heating is prolonged after the complete conversion of silicon to silica during the first evaporation, the beaker is attacked and silicon is taken into solution whence it is precipitated at the second evaporation and high results are obtained which have proved to be due to excess silica. Examples of this phenomenon are given in Table IV.

TABLE IV.

	11.4 standard.	2.66 standard.
Clear	11.40	2.66
Clear 2 mins. .. .	11.40	2.66
Clear 4 mins. .. .	11.43	2.78
Clear 6 mins. .. .	11.47	2.86
Clear 8 mins. .. .	11.84	3.00
Clear 10 mins. .. .	12.17	4.56

It will, therefore, be seen that it is imperative not to leave the solution heating for more than 2 minutes after the conversion of silicon to silica during the first evaporation.

Details of suggested modification of the method

For contents of silicon less than 4% take a 2 gram sample, for higher ranges (5–15%) take a 1 gram sample whilst for the highest ranges (15–25%) take a 0.5 gram sample. The quantity of acid taken is 80 ml. and this is made up of 30 ml. H_3PO_4 (S.G. 1.7), 40 ml. HNO_3 (S.G. 1.4), and 10 ml. H_2SO_4 (S.G. 1.84). For 0.5 gram samples use only 60 ml. of this acid mixture.

Attack the turnings in an 800 ml. tall form Pyrex beaker and allow the violent reaction to subside. Place the beaker on a hot plate with a cover glass on until frothing ceases and any material adhering to the walls has fallen off; do not wash down. Then remove the cover glass and continue heating until conversion is complete; 0.1 gram ammonium nitrate is added to clear any colloidal sulphur and the beaker removed and allowed to cool somewhat. Add cautiously 100 ml. of 20% v/v hydrochloric acid containing 0.1 gram cobalt nitrate ($Co(NO_3)_2 \cdot 6H_2O$) and evaporate down to colour change to clear blue. Do not leave on hot plate at this stage for more than 2 minutes. Allow to cool, dilute with 400 ml. boiling water,* an accelerator may be added if desired, and boil the solution for five or ten minutes. Filter through a Whatman No. 541 or similar paper, wash free of acid with boiling water, dry, ignite in a platinum crucible and weigh when cool. To be quite certain of the purity add 2 drops of sulphuric acid, and an excess of hydrofluoric acid and after gentle evaporation ignite, cool and re-weigh. The difference in the weighings is $silica \times 0.4672 = silicon$. After some practice the volatilisation of the silica may be abandoned for routine work, as the impurities are negligible in most cases if washing is thorough.†

* Boiling water accelerates filtration in a remarkable way. Accelerators coagulate the silicic acid and are useful but not essential.

† If all the phosphoric acid is not removed by washing, the platinum crucibles will be badly attacked.

If the alloy should be very low in iron content, e.g., silicon hardeners made from virgin aluminium, the addition of a little ferric chloride (0.2 gram.) is advised to accentuate the colour change with cobalt nitrate.

To give an idea of the accuracy of this method a few results compared with these found on the same melt by colorimetric method² are given below in Table V.

TABLE V.

Melt No.	Type	Modified Fuchshuber.	Colorimetric method.	Regelsberger.
2470. . . .	L33	12.39, 12.39, 12.29	12.45, 12.30, 12.25	—
KR.108.A . .	DTD.324	10.90, 11.03	11.10, 11.0	—
KR.130.A . .	DTD.324	11.06, 11.08	11.05, 10.85	—
KR.134.A . .	DTD.324	10.97	11.05, 11.25	—
KR.147.D . .	DTD.324	11.00	10.95, 10.95	—
KR.149.D . .	DTD.324	11.15	10.90, 10.85	—
BK.5	DTD.424	7.67	7.65	—
MJ.213 . . .	L33	14.48	14.30	—
TF.891 . . .	DTD.424	6.13	6.20	—
PJ.189 . . .	DTD.424	5.31	5.14, 5.36	5.30
B.6971.A . .	RR50, DTD.133.B.	2.27, 2.35	2.30	—

Addendum.—Since the above paper was written an abstract of a paper published in Russia, dealing with a modification of the Fuchshuber method has been brought to our attention.⁶ This modification seems to consist of adding a 1% solution of gelatin to the precipitated silicic acid to aid filtration. We should like to point out that this modification was tried out in our laboratories and elsewhere⁷ in 1941 before the cause of slow filtration was understood. It certainly speeded up such "sticky" precipitation but did not, of course, correct the erroneous results obtained so often from such precipitations and it was therefore abandoned. In cases where the correct stage has been reached it is entirely unnecessary to add gelatin, and the addition of gelatin does not, of course, in any way affect the other causes of error. It is only fair to say that we have not read the full original paper by these Russian workers.

These investigations were made in the laboratories of Messrs. International Alloys Limited, and we wish to thank the directors of this company for permission to publish.

⁶ N. S. Nikolov, Zavod. Lab. 1941. 536–538.
⁷ S. Torrance, G. A. Harvey & Co. (Private communication).

Obituary

It is with regret that we report the death of Lt. N. J. Mander, 2nd Battn., The Buffs, who, until the outbreak of war, was the publicity manager at the London Office of Aluminium Union, Limited. Mr. Mander died of wounds in Burma on the 31st January, 1945, and the loss of this promising young man will be keenly felt throughout our whole organisation.

Change of Name

BIRMINGHAM ELECTRIC FURNACES LIMITED, of Tyburn Road, Erdington, Birmingham, inform us that they have decided to change their name to BIRLEC LTD. Their trade mark, "Birlec" has been established for many years, and it is felt they are already more widely known by this shortened title.

The company, a subsidiary of The Mond Nickel Co., has pioneered all types of industrial electric heat-treatment and melting furnaces in this country and, in addition, manufactures specially designed gas furnaces, induction heating apparatus and drying equipment.

We are informed that policy, management and personnel will not be in any way affected by the change.

The Institute of Metals

Annual General Meeting

Despite the fact that members of the above Institute on the abeyance and suspense list due to the war, and who are not now counted in the total membership, the numbers continue to increase and have now reached a total of 2,500. This is an indication of the increasing interest taken in the work of this Institute, and in the progressiveness of the Institute in serving the needs of the trades its members embrace. A brief summary is given here of the annual general meeting, held in London, on March 14, in the Hall of the Institute of Mechanical Engineers.

THE thirty-seventh annual general meeting of the Institute of Metals was held in the Hall of The Institution of Mechanical Engineers, Storey's Gate, London, S.W.1, on March 14, 1945, at 10 a.m., the president, Dr. W. T. Griffiths, occupying the chair.

REPORT OF COUNCIL

THE PRESIDENT: We are slowly proceeding towards peace-time conditions, by starting this meeting early in the morning and continuing it all day. The Council considered a two-day meeting, but the difficulties of travel and of accommodation in London were against it.

We have had a most successful year in 1944. Our membership continues to increase. We have modified the method of recording our membership in the Report, and have taken out of the total number those who are on our abeyance and suspense list; in other words, those who because of the war and their absence on Service or the fact that they were living in occupied countries were unable to act as members. We hope that many of those who have been in occupied countries will rejoin us now that Europe is being liberated. In spite of that our numbers still increase, and have now reached a total approaching 2,500.

We have lost by death a number of old and prominent members—eighteen during the period covered by the Report of Council. I would specially refer to the passing of our good friend Mr. W. M. Corse, who for 22 years was our Corresponding Member in the United States of America. He passed away last summer. We also heard with regret that our one-time honorary Corresponding Member in Canada, Professor A. Stansfield, has passed away.

Since the beginning of 1945, we have been sorry also to hear that three great friends of ours, Dr. G. D. Bengough, F.R.S., Engineer Vice-Admiral Sir George Preece, and Mr. Percy Pritchard, have also left us, and recently we had news that that young and brilliant metallurgist in Sweden, Dr. Phragmen, had also been taken.

The Council also records with much regret the deaths of: H. G. Atkinson; C. W. Buchan; Commander Sir Charles Craven, Bart., O.B.E.; Sir Colin Fraser, Kt.; W. Villa Gilbert; Peter Griffiths; J. W. Harper; R. S. Hawke; R. G. Johnson; N. Kerjundzie; A. G. Melroy; A. E. Shorter, M.B.E.; Dr. T. Swinden; F. T. F. Toller and J. Webster. The sympathy of the Council is extended to the relatives of the deceased members.

The Council are confident that they are voicing the opinion of the members in placing on record the appreciation of the Institute of the valued services which he rendered as secretary for 36 years, during 30 of which he served also as editor. As members know, arising out

of his retirement, and with the very friendly co-operation of the Iron and Steel Institute, we were able to offer the secretaryship thus rendered vacant to Mr. K. Headlam-Morley, who for some years has been secretary of the Iron and Steel Institute. He has accepted, and I feel that I should say here how much we are indebted to him for his efforts during the year that has passed. We are indebted to Mr. Headlam-Morley for the energy with which he has tackled his double job and for the success with which he has carried it out.

Soon after Mr. Headlam-Morley joined us it became clear that there would be great advantages if we could further join forces with our friends of the Iron and Steel Institute, and after some very friendly discussions with them it was decided that we should appoint Mr. A. E. Chatten, the assistant secretary of the Iron and Steel Institute, as our assistant secretary too and that Mr. N. B. Vaughan, who has so ably carried on during the war as assistant editor of our *Journal*, should assist the Iron and Steel Institute in an editorial capacity. The stenographic and other staffs of the two Institutes are working together for both Institutes very harmoniously, and I am sure that the arrangements which have been made, and under which both Institutes, of course, still retain their separate identity, lead to increased efficiency and increased economy of working.

National Certificates in Metallurgy

At the time of the last annual general meeting we had hoped that during the year National Certificates in Metallurgy would be instituted. Unfortunately, unforeseen difficulties of organisation made that impossible, but now the Joint Committee of representatives of this Institute, the Iron and Steel Institute, the Institution of Mining and Metallurgy and the Ministry of Education has been set up, and it is fully expected that a scheme will shortly be issued which will come into operation at the next school session, the courses starting in September and the first examination being held in 1946.

The Council continues to co-operate in matters appertaining to the education of the metallurgist, and during the year it accepted an invitation to give evidence before the Higher Technological Education Committee of the Ministry of Education. In co-operation with other metallurgical institutes, a Joint Education Committee has been set up to advise and assist us in this matter in the future.

Institution for Metallurgists

The Council and the Council of the Iron and Steel Institute took steps which resulted in a number of our leading metallurgists coming together to form a Provisional Council and taking the initial steps to set up an Institution. Those steps we expect to result very shortly

in the establishment of the institution, which, it is suggested should be known as the Institution of Metallurgists. It is expected that the new institution will work in close collaboration with the Institute of Metals and the Iron and Steel Institute, and these Institutes are assisting in all the ways they can in providing secretarial and other help.

Election of Officers and Members of Council

The election of officers and members of Council was announced as follows:—

President: Dr. W. T. GRIFFITHS.

Vice-Presidents: Mr. ROOSEVELT GRIFFITHS, M.Sc.
Dr. J. L. HAUGHTON.

Hon. Treasurer: Mr. H. S. TASKER, B.A.

Members of Council: Major C. J. P. BALL, Dr. L. B. PFEIL, A.R.S.M. and Dr. C. J. SMITHELLS, M.C.

Also nominated for the Council was Engineer Vice-Admiral Sir Frederick Turner, K.C.B. and in the ordinary course he would have been elected. Unfortunately, on medical grounds, he has been ordered complete rest and would not be able to take an active part in the work of the Institute. He suggested that his nomination should not be brought forward on this occasion. A vacancy thus exists on the Council and the Council will proceed at its next meeting to consider the question of filling that vacancy by co-operation.

Presentation to Mr. G. Shaw Scott

The president took the opportunity of expressing the appreciation of the Institute for the valuable services rendered by Mr. Shaw Scott over a period of 36 years, the whole time as secretary of the Institute and during a large part of the time as editor of its *Journal* also. During those 36 years, said the president, Mr. Shaw Scott did not merely carry out loyally the duties of an officer of the Institute, but made himself a friend to hundreds of members.

One would suppose, continued the president, that to a large number of our members, and particularly of our members overseas, "G. Shaw Scott" would be merely a name at the bottom of a letter; but I have been very impressed when meeting these members overseas, as I have been privileged to do during the war period and before, to notice how often they would find time to say "And how is my good friend Shaw Scott? I have never met him, but he has helped me in so many ways on so many occasions."

Thus it was that when it became known that Mr. Shaw Scott was about to retire, many members intimated that they would like to take some personal part in an expression of appreciation to him for his services. At the Council's request, a little note was circulated last summer, to which the response has been such that it has demonstrated without doubt the wide and deep regard in which Mr. Shaw Scott is held by the members of the Institute. With part of the money so received, a silver coffee set has been obtained; the remainder is in the form of a cheque, in this envelope.

In making the presentation, the president continued, "Mr. Shaw Scott, on behalf of your many friends in the Institute I ask you to accept this coffee set and this envelope as an expression of their regard for and gratitude to you for your friendship and service to them all, collectively and individually; and in that I am sure that the members would like me to include our best wishes to you for a long, happy and contented retirement. They

would join with that the name of Mrs. Shaw Scott whom we have so often been glad to have with us at meetings in the past, and who, we are sure, has been a source of strength to you in sustaining you in your services to us all." (*Applause.*)

Mr. G. SHAW SCOTT, who was received with prolonged applause, said: Mr. President and fellow-members, your splendid gift, and your all too kind words, sir, are deeply appreciated. In saying that, I speak for myself and also for my wife, to whom you have just paid so graceful a tribute. She has played no unimportant part in the progress of the Institute since that day when she threw in her lot with mine, soon after the Institute was founded.

These beautiful pieces of silver will form a most useful addition to our new home, where they will also serve as a constant reminder of the Institute of Metals and of our many friends within the Institute, of whom the president has so kindly spoken. The handsome cheque, too, will be used domestically as soon as it becomes possible to purchase certain articles now not in supply, or obtainable only after much searching or perhaps at an unduly inflated price.

As an indication of the difficulty that prevails to-day in securing the objects of one's desire, it may be mentioned that, thanks to the thoughtful co-operation of my old friend and colleague Mr. Headlam-Morley, than whom I can imagine no more worthy successor to the secretaryship of the Institute, we were able to visit various shops with a view to selecting a personal gift for to-day's presentation. A chiming clock was bracketed equally with a silver coffee set, and an option obtained to permit of a few day's meditation. Alas, when the time-piece was called for it was gone, taken not by a more expeditious purchaser, but by a highly-discriminating clock-conscious burglar. There followed a similar delayed-action period with regard to the most effective gift now on the table before you, and here too it was nearly a case of "He who hesitates is lost," but in this case the cause was enemy action. A piece of the rocket which wrecked a near-by market descended through the skylight to the floor of the silver-smith's showroom, coming to rest inside the very nice case in which the present choice gift was displayed, but happily without causing any appreciable structural or other damage. Truly the way of the seeker after knowledge regarding the good things of this world is not without its tribulations!

But the end has most certainly justified the means in this case, for Mrs. Shaw Scott and I have been rewarded in our search by receiving from your hands, sir, these very beautiful examples of the silversmiths' art, objects which, after all, have a closer connection than has an ancient horological piece with the Institute of Metals. We are united in asking you to accept our warmest thanks for this, for the cheque and for all the good wishes that we have received on my retirement from an Institute which, by the way, began its corporate life in this very room, which I have been privileged to serve since its inception, and of which the Council have done me the great honour of appointing me secretary emeritus, thus securing a continued connection with my now grown-up and prosperous baby of 1908 right to the end of my days. (*Applause.*)

Presentation of the Platinum Medal for 1945

The PRESIDENT: My next task gives me a double pleasure. Each year since 1938, when my late colleague, mentor and friend, Mr. Barclay was president, the

Mond Nickel Company, his company and mine, have given to the Institute of Metals a medal fashioned from platinum, refined here in London, to be awarded by the Institute for outstanding services to the non-ferrous metal industries. I am indeed proud and pleased to be the one this year to present it on your behalf, and I am doubly pleased in that the recipient chosen this year by your Council is one so well known and so much respected by all of us, a past-president and a Fellow of the Institute, Dr. Richard Seligman. (*Applause.*)

Like many present-day metallurgists, and indeed like more than one of the Institute's previous medallists, Dr. Seligman commenced by studying chemistry. I believe he took his doctorate in that subject. When he had completed his studies, which took him to Heidelberg in Germany and to Zurich in Switzerland, he quickly began to apply his scientific knowledge to research in the metallurgical field, and after a brief period in America he was appointed research chemist to the British Aluminium Company, and his interest in the light metal has continued right up to to-day. Later on we find him setting up his own research laboratory to investigate the possibilities of what was then a novel application, the application of the welding process to aluminium. But he did not stop there. Convinced of the possibilities of the welding process, Dr. Seligman re-entered industry and founded that now widely-known firm, the Aluminium Plant and Vessel Company.

In taking this step, he did not leave behind his scientific and research outlook. We are hearing a great deal to-day about the application of research in British industry, and also about the importance of the export trade to British industry. I suggest that Dr. Seligman has demonstrated full well how an international reputation can be built up for a British firm on the basis of metallurgical and related research. Throughout the years since 1910, his pioneer approach to the many problems involved in the construction of plant for the chemical and related industries has led to the development of many a new technique and many a new design, and to a notable increase in our knowledge and understanding of the numerous factors involved in the employment of metals for the containing and conveying of corroding media of numerous kinds.

His attention, of course, has not been confined solely to aluminium but has ranged over most materials of construction, although I think it is true to say that he has been particularly concerned with studies of the corrosion-resisting materials—metals and alloys—and their utilisation in circumstances where complete freedom from contamination of the product is necessary. Those studies have led to a considerable expansion of our knowledge of the factors involved in corrosion, and, in addition to our own industry, the food industry, the chemical industry and numerous others owe him a debt for his work in this field of corrosion and plant construction.

Dr. Seligman's contributions to the non-ferrous industry, however, are not confined only to what he has done in furtherance of his own business. He has played a prominent part in the support and guidance of research in the general metallurgical field, and those who know something of his activities will understand and appreciate how much he has done to stimulate work by others, the results of which have been of the greatest impor-

tance to our industry and to our science. Before the war he spent not a little time on the Continent and in America, and he has done much to promote international co-operation and understanding between metallurgists everywhere. He has added to our indebtedness by accepting the invitation of the Council to present to-day's address, and has chosen as his subject, "The Organization of Metallurgical Research."

In making the presentation, the president added, Dr. Seligman, on behalf of the Institute it gives me the greatest possible pleasure to present to you the Institute of Metals Medal as an indication of our appreciation of the outstanding services you have rendered to the non-ferrous industry and of our esteem and gratitude for all you have done for all of us. (*Applause.*)

Dr. RICHARD SELIGMAN: Eight years ago, it fell to my lot to propose the name of the first Medallist. I remember writing to my friend, Dr. Desch that we must be most careful how we chose the first Medallist; it would not matter so much about the others, but we must be careful to choose only the very best for the first, so that all who came after might realise the immensity of the honour which was being conferred upon them. I named Sir William Bragg; and you know me too well to think it could possibly have occurred to me that I should stand where Sir William Bragg has stood. But it does show that there are more ways than one in which a man can serve the art to which we all here are devoted.

In the letter which Mr. Headlam-Morley wrote to me, giving what I might call the citation for this honour which you have done me, there was one word, a very small word, which gave me particular pleasure. It was the little word "and," and you have emphasised the meaning of that "and" this morning. Once before from this platform I told the Institute that all my working life had been spent in trying to apply to industry those lessons which I had been taught in the early days by distinguished scientists. If the Council of the Institute are right in their judgment—and I am the last to question it to-day!—then I have also been successful in serving the science as well as the industry. That is the meaning of the word "and," and that is why that little word fills my cup to the brim.

I thank the president most cordially for the very kind words in which he has expressed the feelings of the Institute to-day. As he has said, this has been one of the main interests of my working life, and I am deeply grateful for the honour you have done me. (*Applause.*)

Professor R. F. Mehl

Before proceeding to a discussion of papers which were presented at the meeting, the president, on behalf of the members, welcomed a member from overseas, Dr. Robert Mehl, the Professor of Metallurgy and Director of Research of the Carnegie Institute of Technology in Pittsburgh, who arrived in England just prior to the meeting, and who was present. On many occasions, said the president, he has shown kindnesses to visitors from this country to America, and it is a pleasure to have the opportunity of repaying some of that debt. Dr. Mehl is a prominent member of the corresponding Institute in the United States, the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers, the American Society of Metals, and the American Society for Testing Materials.

TECHNICAL SESSION

THE remainder of the morning was devoted to the discussion of technical papers and was resumed during the afternoon. In all six papers were arranged for presentation: "Binary Equilibrium," by A. J. C. Wilson; "An Exploration of the Problem of Superheating in Magnesium-Base Alloys," by F. A. Fox and E. Lardner; "The Influence of Centrifugal Casting (Horizontal Axis) upon the Structure and Properties of Metals," by L. Northcott and V. Dickin; "Corrosion of Galvanised Coatings and Zinc by Water Containing Free Carbon Dioxide," by L. Kenworthy and Myriam D. Smith; "A Quantitative Study of Soft Soldering by Means of the Kollagraph," by L. G. Earle; and "The Metallographic Examination of Aluminium-Rich Alloys" by N. H. Mason, C. J. Metcalfe and B. W. Mott. Some of the papers are briefly referred to in the following notes.

Binary Equilibrium

THERMODYNAMIC reasoning leads to a number of rules governing the form of equilibrium diagrams. Of these rules, only the phase rule seems universally recognized, the others being sometimes regarded with suspicion. In this paper, by A. J. C. Wilson, an attempt is made to derive in a short and reasonably simple manner all the known rules governing binary equilibrium diagrams, with the hope of providing a basis for discussion to establish their validity or otherwise. Thermodynamic derivations are given of the known results governing binary equilibrium:—

1.—In eutectic (oid) and peritectic (oid) reactions the phase boundaries inflect towards the temperature horizontal at the point where they touch it.

2.—In a polymorphic reaction (*e.g.*, maximum or minimum in the liquidus) the boundaries of both phase-fields are horizontal at the point of contact.

3.—The boundary of a solubility gap is horizontal at the point of closure.

4.—When a polymorphic reaction takes place in one of the pure components, the initial slopes of the phase boundaries meeting at the transition temperature differ by L/RT^2 , where L is the latent heat and T the absolute temperature of the transition, and R is the gas constant. Rules 2 and 4 do not seem to be well known.

An Exploration of the Problem of Superheating in Magnesium-Bronze Alloys

THE superheating effect shown by magnesium alloys is well known. The process of superheating is one in which the casting alloy, of the magnesium-aluminium type, is heated to, and held for some appreciable time at, a temperature exceeding 840°C . The metal is then cooled quickly to the casting temperature, which usually lies between 720°C and 780°C . The effect of this exposure to a high temperature is to produce a refinement of the grain of the casting. Since the mechanical properties of these alloys are sensitive to changes in grain-size, a fine-grained structure is highly desirable in the casting, the properties of which are considerably better than when the grain-size is large.

This paper by F. A. Fox and E. Lardner records and discusses various experimental results concerning phenomena associated with the superheating of magnesium-base alloys. It is shown that the grain-refining

effect is confined to alloys containing aluminium, and that tendencies to grain-coarsening are introduced if the superheating time is too long or the temperature too high. Data are given relating tensile properties to grain-size in various aluminium-containing alloys. It is also shown that the microstructures of superheated alloys differ characteristically from those of the unsuperheated material, and that this difference persists even after solution treatment, the unsuperheated alloy giving a mixed grain-size. Grain-sizes are recorded for an alloy, superheated and unsuperheated, cast as rods of various cross-sections. It is shown that stirring just before casting does not eliminate the grain-refinement effect of the superheating. A discussion of the results follows, and some observations on possible theories of grain refinement are made.

The Influence of Centrifugal Casting (Horizontal Axis) upon the Structure and Properties of Metals

SINCE experience with centrifugally cast materials had shown that certain peculiarities in structure could occur owing to the special method of casting, a comprehensive investigation was carried out in the Armament Research Department into the metallurgical aspects of the centrifugal-casting process as applied to a wide range of alloys, using both horizontal- and vertical-axis machines. In this paper, by Dr. L. Northcott and V. Dickin, the work described was devoted to the centrifugal casting of thick cylinders of three non-ferrous alloys—*viz.*, aluminium, 6%; copper alloy, 6%; tin, bronze and 70 : 30% brass, using a horizontal-axis machine.

The casting conditions were varied in respect of mould speed, casting temperature, rate of pour, and mould temperature, and the castings were examined to determine the influence of these factors upon structure. Small stationary ingots were prepared at the same time for comparison. The crystal size of the centrifugal castings was very much smaller than that in the stationary ones and was less susceptible to changes in casting conditions. In the centrifugal castings, small crystal size was favoured by a low casting temperature and mould temperature, a high mould speed, and a slow rate of pour.

There was found to be an optimum speed of rotation of the mould which gave a uniform structure free from pronounced segregation. At much lower speeds the delay in pick-up of the molten metal in the mould resulted in splashing of the metal, which gave rise to coarse circumferential zoning and roughness of the cylinder bore. High mould speeds led to a finer structure, but this was liable to be marred by circumferential rings of segregate associated with mould vibration. The damaging effect of vibration has been confirmed by tests on vibrated unrotated ingots.

Chemical analyses showed little variation in average composition of samples taken radially from castings of 70 : 30 brass, but the aluminium-copper alloy and the bronze castings showed inverse segregation, the outer portions of the castings being rich in copper and tin respectively. Solidification of these thick cylinders proceeded in general from the outside towards the inside, the bore position being that where solidification finally occurred; examples of irregular solidification were, however, observed.

Influence of Tempering Temperatures upon the Strength of Heat-Treated Steels

By D. W. Rudorff

By the proper heat-treatment of steels it is possible to obtain a combination of properties ; thus, tempering a hardened steel will increase its toughness at the expense of the hardness property, but the tempering temperature is known to have considerable influence on the strength of steels and this review of an investigation on the subject deals with results of tests on two carbon steels and two low-alloy steels.

A RECENT investigation by A. Krisch* was concerned with the systematic study of the influence of the tempering temperature upon the strength of a number of structural steels, including two carbon steels of 0.43 and 0.56% C and ten steels of 0.16-0.5% carbon with 0.2-1.6% Si, 0.5-2.2% Mn, 0.2-5% Cr, and 0-0.21% V. The actual composition of these steels and the respective heat-treatments applied are listed in Table I. In order to take into account the mass effect, rods of both 60 mm. and 30 mm. diameter were tested. The temperatures listed were those recommended by the steel makers who supplied the various materials. Within the respective ranges specified by the makers, the tempering temperatures were progressively varied in steps of 50° C. For each tempering temperature, held for three hours, a separate test piece was used, its length being 245 mm. in the case of the 60 mm diameter material and 427 mm. in the case of the 30 mm. diameter material. Pieces tempered at 500° C. and higher were water quenched from 500° C. in order to avoid temper brittleness, while the specimens tempered at temperatures below 500° C. were quenched from the temperature of draw. In all cases this quench was followed by a three-hour anneal at 300° C. for stress relieving. After measuring the hardness of the pieces two 10-mm. test bars were cut from surface and core respectively, to be used for the determination of the 0.2% yield point, the ultimate tensile strength, the

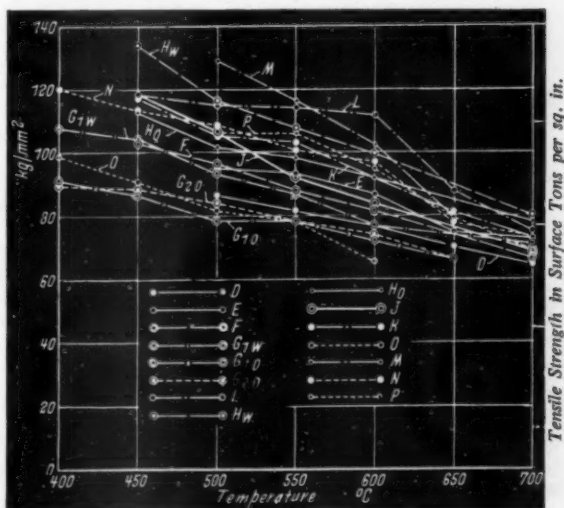


Fig. 1.—Influence of tempering temperature upon tensile strength in surface of 60 mm. rounds.

elongation, as well as the reduction in area. Two test bars of 10 × 10 × 55 mm. with a 3 mm. notch of the Charpy keyhole type were also prepared from surface and core material respectively. The test bars prepared from the 60 mm. diameter material exhibited a steady decrease in surface hardness with increasing tempering temperature, and also showed different variations in hardness throughout the section of the various tempering temperatures. These variations in hardness were found to be quite small in most pieces tempered at high temperature, but were found to increase with lower temperatures of draw. The ultimate tensile strength values found in the surface of the 60-mm. bars with different tempering temperatures are charted in Fig. 1. It is seen that for identical temperatures of draw, the plain carbon steels and the

* Stahl und Eisen, 1944, No. 7, p. 105.

TABLE I.—HEAT TREATMENTS APPLIED.

Steel	Dia. mm.	C	Si	Mn	P	S	Cr	Mo	Ni	V	Quench from deg. C.	Temper- ing temp., deg. C.
D	60	0.43	0.27	0.55	0.025	0.025	0.15	0.05	0.13	—	840 Wx	500-700
E	60	0.56	0.25	0.51	0.015	0.008	0.08	0.05	0.10	—	880 Ø	500-700
F	60	0.32	0.33	1.33	0.019	0.015	0.13	<0.05	0.05	—	830 W	450-700
G1W	60	0.32	0.28	1.68	0.023	0.022	0.17	<0.05	0.16	—	830 W	450-550
G10	60	0.32	0.28	1.68	0.023	0.022	0.17	<0.05	0.16	—	780 W	400-700
G20	60	0.32	0.28	1.68	0.023	0.022	0.17	<0.05	0.16	—	780 W	400-500
G30	60	0.32	0.28	1.68	0.023	0.022	0.17	<0.05	0.16	—	820 Ø	400-650
H	60	0.16	0.21	2.22	0.017	0.009	0.10	<0.05	0.06	Traces	780 W	400-500
HW	60	0.16	0.21	2.22	0.017	0.009	0.10	<0.05	0.06	Traces	890 Ø	400-650
HO	60	0.32	1.55	1.29	0.03	0.015	0.33	<0.05	0.08	—	850 W	450-700
J	60	0.3	0.34	0.75	0.033	0.030	0.95	<0.05	0.11	<0.05	850 W	450-700
K	60	0.3	0.34	0.75	0.033	0.030	0.95	<0.05	0.11	<0.05	880 Ø	450-700
L	60	0.35	0.24	0.71	0.017	0.019	1.12	<0.05	0.05	<0.05	850 W	400-700
M	60	0.35	0.54	1.02	0.016	0.008	1.05	<0.05	0.17	—	880 Ø	450-700
N	60	0.5	0.24	0.63	0.016	0.029	1.05	<0.05	0.14	0.13	920 Ø	500-700
P	60	0.28	0.34	0.54	0.015	0.016	2.49	<0.05	0.06	0.21	860 W	500-650
	30	0.39	0.38	1.54	0.015	0.005	0.14	<0.05	0.11	0.15	840 W	400-700
	30	0.28	0.28	1.12	0.019	0.006	0.77	0.08	0.12	0.14	804 W	350-600
	30	0.28	0.28	1.12	0.019	0.006	0.77	0.08	0.12	0.14	880 W	500-700

PER CENT.

W: Water, Wx: water with 0.83 % NaCl. Ø: Oil.

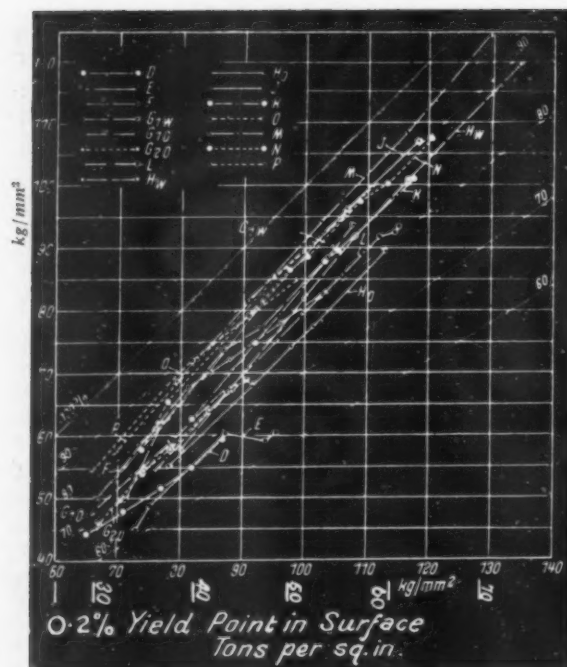
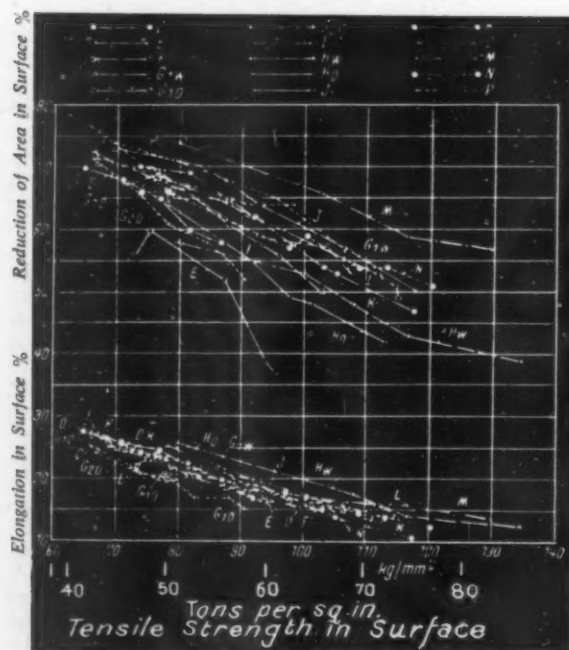


Fig. 2.—Variation of the 0.2 Y.P. with the tensile strength in the surface of 60 mm. rounds.

steels alloyed with manganese exhibit lower strength as compared to the Cr-alloyed steels; but in this connection the influence of the carbon content should not be overlooked. In the range of tempering tem-

Fig. 3.—Variation of elongation and reduction of area with the tensile strength.



peratures below 550° C., the highest ultimate tensile strength is recorded for the Cr V steel M, while in the range above this temperature the Cr V steel L shows highest tensile strength of the materials considered.

The relation of yield-point to tensile strength, that is, the elastic ratio in per cent. as it was found for the various materials, is charted in Fig. 2. It is seen that in no case does the elastic ratio of the plain carbon steels reach 70%, while the alloyed materials in nearly all cases show elastic ratios above that figure. Also with a few exceptions the yield-point is seen to rise at a faster rate than the tensile strength. The highest elastic ratio is therefore obtained in the case of the highest tensile strength, that is, of the lowest temperature of draw. The Cr-steel J and the Cr-V steel M are seen to possess yield-points greater than 90% of the ultimate tensile strength, while even with the lowest tempering temperature the yield-point of Mn-Si steel H does not amount to more than 89% of the tensile strength.

Considering the values of elongation and contraction of area of the various steels charted in Fig. 3, no such pronounced superiority of the alloyed materials is evident. Here steel D must be grouped with the steels of greatest elongation within the tensile strength range of 41.275-50.8 tons per sq. in., showing values superior to those exhibited by the Cr and V steels J and P respectively. As the steels J and P show practically constant elongation throughout almost the entire strength range investigated, the elongation cannot be considered as a distinguishing characteristic. More suitable in this regard would appear to be the reduction of area. Referring to Fig. 3, it is seen that with increasing tensile strength the reduction of area decreases at a considerable higher rate than the elongation. For identical values of tensile strength the plain carbon steels D and E are shown to possess the smallest reduction of area; while in the range of tensile strengths exceeding 63.5 tons per sq. in. the Cr and V alloy steels J and P. are seen to possess greater reduction of area than the Mn and Si steels F and H. Referring to the Cr V steel M with 82.15 tons per sq. in. ultimate tensile strength, this material still has a reduction of area of more than 55% as compared to a value of 40% recorded for the Mn-Si steel H.

From the aspect of comparative deformability, the notched impact strength must be considered as particularly important. Referring to Fig. 4, the Cr V steel M is seen to possess the highest impact strength over the range from 50.80 to 82.15 tons per sq. in. ultimate tensile strength. The steepest decline of its impact strength takes place between 63.5 and 73.03 tons per sq. in. ultimate tensile strength, in which range equal impact strength values are obtained both with the Mn V steel N and the Cr steel J. The highest tensile strength of 85.1 tons per sq. in. is obtained with the Si Mn steel H, which at this tensile strength possesses an impact strength exceeding 28.92 ft. lb. All results reviewed so far refer exclusively to test bars taken from the surface of the 60 mm. rounds. In order to gain an insight into the variations in strength throughout the section of the material, the test results found with the test bars taken from the core of the rounds have also been charted.

In Fig. 5 is shown the difference prevailing between surface and core tensile strength as plotted against the surface strength. Generally this difference will increase

with the tensile strength as such. A core strength superior to the surface strength was found in only one case. Of the two plain carbon steels investigated, steel D exhibits greatest uniformity of strength through the section. In this respect it is excelled only by a few alloyed steels. This high degree of uniformity (differences amounting to no more than 2.5 tons per sq. in.) must be attributed to the fact that this material was the only one to be hardened with water containing 0.83% NaCl. With the other carbon steel (E) the difference amounted to almost 6.35 tons per sq. in. at 63.5 tons per sq. in. U.T.S. in the surface. It would therefore be difficult to keep this material within the usually specified maximum difference of 9.325 tons per sq. in. if a tensile strength of 63.5 tons in the core is called for. Among the alloy steels, this uniformity of the Mn steels is little superior to that recorded for the

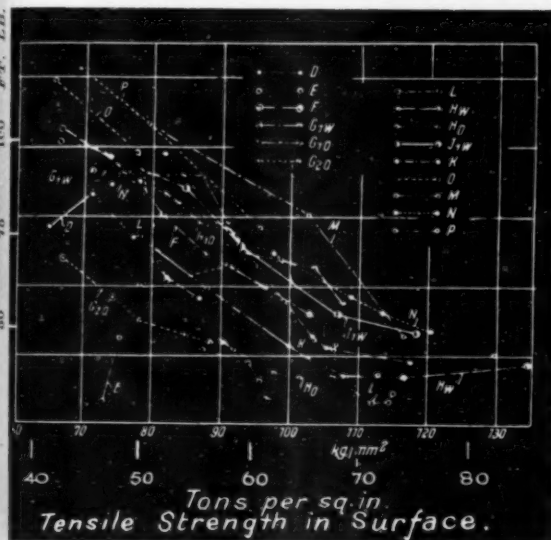


Fig. 4.—Variation of impact strength with tensile strength.

carbon steel E. More favourable results were obtained with the Mn Si steel H, exhibiting a variation in tensile strength of 6.35 tons per sq. in. across the section when having a surface tensile strength of 76.2 tons per sq. in. Greater uniformity is also shown for the oil-quenched specimens, but these do not of course obtain the tensile strength values obtainable with the water quench. The uniformity of the steels alloyed with chrome and vanadium approximates to that recorded for the Mn and the Mn Si steels G and H. Among these steels the Cr V steel L is remarkable for its uniformity. In the range of tensile strengths exceeding 69.85 tons per sq. in., steel J shows smallest and the steels H, N, and P greatest uniformity.

The 0.2 yield-point is known to vary throughout the cross section to a greater extent than the tensile strength. It is therefore to be expected that the test bars taken from the core will show a lower elastic ratio than those taken from the surface. In Fig. 6 the 0.2% yield-point of the specimens taken from the core is plotted against the ultimate tensile strength as found in the surface.

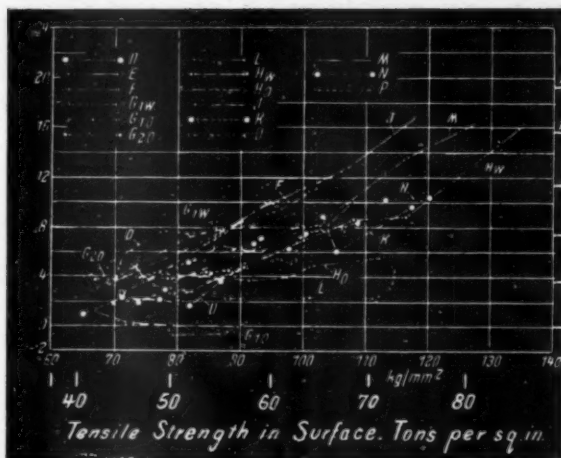
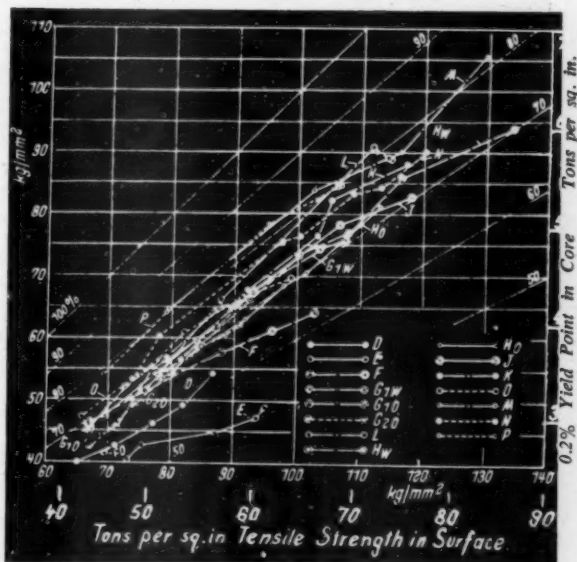


Fig. 5.—Difference between tensile strength in surface and core versus tensile strength in surface of 60 mm. rounds.

The elastic ratio lines drawn in Fig. 6 therefore indicate the elastic ratio of the core test bar multiplied by the ratio of tensile strength of the core/tensile strength of the surface. For the two carbon steels D and E this ratio approximates to 60–50%, the material higher in carbon (E) showing the lower ratio. Also this ratio is seen to decrease with rising tensile strength while in Fig. 2 it was found to increase.

As will also be seen from Fig. 6, the Mn and the Mn Si steels possess elastic ratios approximating to 70% for tensile strengths exceeding 63.5 tons per sq. in., the Mn steel F being the sole exception. For the Mn steel H, an elastic ratio of 70% is still recorded for a surface tensile strength of 82.15 tons per sq. in. Still higher elastic ratios are found for the Cr and V steels K and P.

Fig. 6.—Influence of tensile strength in surface upon 0.2% Yield Point in core of 60 mm. rounds.



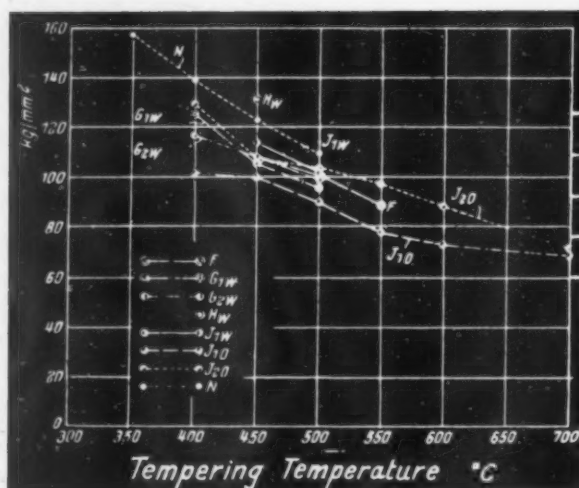


Fig. 7.—Influence of tempering temperature upon U.T.S. in surface of 30 mm. dia. rounds.

which average some 78%. The highest elastic ratios are shown for the materials L, M, and P. The V and Cr contents of these materials are therefore reflected by the attainment of a higher yield-point, particularly in the core, and this in addition to the achievement of higher ultimate tensile strength and notched bar impact strength.

So far only the test results obtained with 60 mm. rounds have been reviewed, and reference still remains to be made to the influence of the mass effect as expressed by the diameter of the bar. Obviously the difference between the respective strength values found in surface and core will increase with increasing diameter of the piece, and vice versa it will decrease with smaller

Fig. 8.—Relationship between U.T.S. in surface and 0.2% Yield Point in core of 30 mm. dia. round.

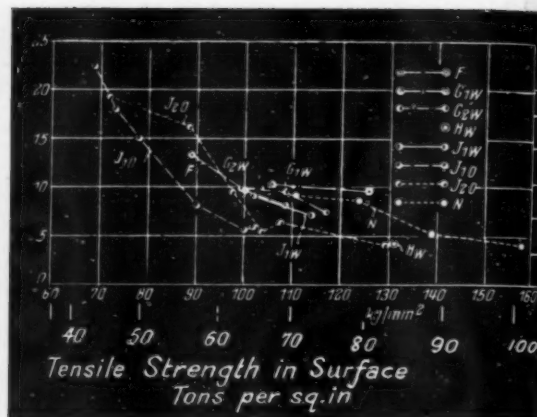
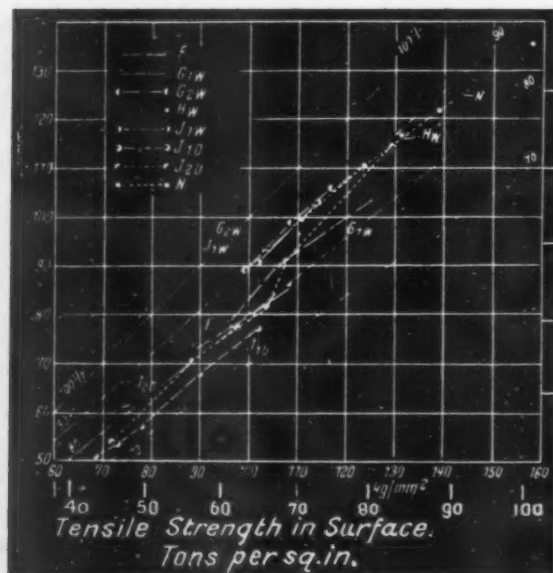


Fig. 9.—Impact strength versus U.T.S. of 30 mm. dia. rounds.

diameters. However, as will be seen from Fig. 7, not only the difference between the respective strength values, but also the absolute strength in the surface varies with the diameter. This relationship was found to be particularly pronounced with relatively low tempering temperatures, the test bars from the 30 mm. diameter material yielding considerable higher tensile strength values than those taken from the 60 mm. rounds.

In most cases the elastic ratio likewise increases with decreasing diameter, with elongation and reduction of area hardly diminishing, in spite of the higher tensile strength. Because of this smaller difference in tensile strength between core and surface, the ratio of core yield-point to surface tensile strength is considerably higher in the case of the 30 mm. rounds as compared to the 60 mm. material. As will be seen from Fig. 8, in the case of the Mn and Mn Si steels, this ratio approximates to 80-90% as contrasted with a ratio of about 70% obtained with the 60 mm. rounds. With the Cr or V alloyed steels, ratios of 85 at highest tensile strength could be obtained from the 30 mm. diameter bars. As evidenced by Fig. 9, this increased tensile strength was not accompanied by any reduction in deformability of the material, the impact strength values remaining satisfactory. In this respect the Mn V steel N is outstanding, combining, as it does, a tensile strength of 101.6 tons per sq. in. with an impact strength of 28.92 ft. lb.

Personal

Mr. James Paton, general manager of The Dowson and Mason Gas Plant Co., Ltd. since 1917 has retired and Mr. L. G. A. Leonard late assistant general manager of Messrs. British Furnaces Ltd. has succeeded him as general manager. The company, however, will continue to receive the benefit of Mr. Paton's long experience as he is retaining his seat on the board of directors.

Dr. C. J. Dadswell, Mr. G. E. G. Gilfillan, O.B.E., Mr. G. C. Grant, Mr. B. Gray, Mr. W. D. Pugh, Mr. H. Scholey, Mr. R. G. H. Taylor and Major E. I. Scott have been appointed special directors of the English Steel Corporation, Ltd. Mr. W. D. Pugh has also been appointed a director of Darlington Forge, Ltd.

Beam Design in the Curvilinear and Plastic Ranges of Stress

A Brief Discussion on Some Basic Principles

By A. Fisher

Deputy Chief Metallurgist, Magnesium Elektron Limited

Considerable interest is being shown in the differences between practical results and present theory as applied in the plastic ranges of stress. In this article the author discusses some basic principles of curvilinear-stress-strain characteristics and emphasises a general feeling that the time is ripe for a re-examination of the bending and torsional theories, particularly the former.

AN increasing amount of interest is being shown in the possibility of modifying strength design formulae to be used for constructional materials having curvilinear stress-strain characteristics. As is well-known, standard text book design formulae for bending or torsional stressing systems are based on the assumption that stress is proportional to strain—i.e., that the stress-strain curve is rectilinear within the limits of stress used. While this is generally true for ferrous materials, it is far from being true for non-ferrous materials, and during the past few years some attention has been paid to the question as to whether and how much, practical results are affected by the discrepancy introduced by this particular assumption. 4, 5, 6, 7

In contemplating the actual differences between practical results and present theory, it seems that other factors must be operative besides that mentioned above, and a general feeling is in the air that the time is ripe for a re-examination of the bending and torsion theories, particularly the former.

It is the object of this article to deal in an explanatory manner with the points raised by the curvilinearity of stress-strain curves, discussing the problem in non-mathematical terms; to mention a few other forgotten factors which may also be influencing results in both the plastic and elastic ranges, and to draw attention to the need for a systematic exploration, both theoretical and practical, into the whole problem.

The Stress-Strain Curve

Whenever a piece of metal (or any other substance) is put under load, a change of dimensions occurs in the specimen; no matter how small the load, there will be a corresponding change in dimensions; the relation between this dimensional change and the load producing it can be shown by a graph.

Suppose the piece of metal is a tensile test-bar, loaded gradually in a tensile-testing machine up to the point of final fracture, and that for every increase in load the increase in length of specimen (between the standard gauge length marks) is recorded; then if these two variables be plotted on squared paper, the resulting curve (a load-extension curve in this case) will take a

form characteristic for the material in the condition tested.

A stress-strain curve is similar to a load-extension curve, the only difference being that instead of "load," the "stress" (load per unit area) is used, and instead of "extension," the "strain" (extension per unit length) is used.

Stress-strain curves for the usual metallic constructional materials vary in shape according to the characteristic properties of the materials, but they all have this in common, that they consist of a straight portion followed by a curved portion. Relative to the full length of the curve, the length of the straight portion varies considerably; on very ductile materials it may be so

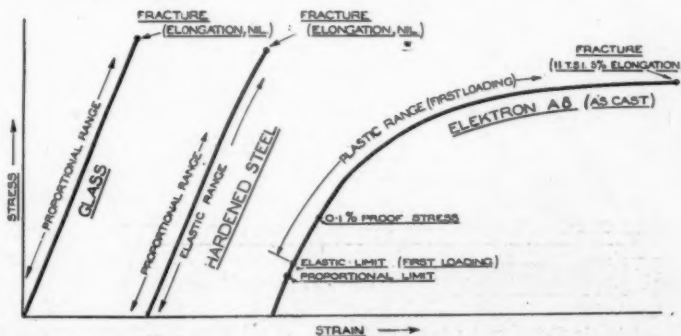


Fig. 1.—Stress-strain curve types. (Diagrammatic.)

short as to be difficult to discover, whilst on some brittle materials it constitutes a large part of the curve, Fig. 1.

At stresses below a certain point on the curve, generally somewhat beyond the end of the straight portion, most materials will be deformed only temporarily; on removing the load, the material will return to its original dimensions. This point, marking the stress at which a permanent deformation first appears, is called the "elastic limit" and as stated, for most materials it lies somewhat beyond the junction between the straight and the curved portions of the stress-strain curve, Fig. 2.

The stress corresponding to the actual junction point is called the "proportional limit" and is obviously the limit of stress which is strictly proportional to strain,—i.e., it represents the limit of Hooke's Law. Elasticity, in the sense of returning to zero deflection after removal

of load, or in other words, freedom from permanent deformation, may thus exist beyond—on some materials considerably beyond—the limit of proportionality. This fact is sometimes overlooked.

The whole range of stress up to the elastic limit is called the "elastic range," and beyond this, the "plastic range." The term "plastic range of stress" is thus concerned with neither plastics nor hot-working of metals; it merely refers to a condition where the stresses induced by loading have gone beyond the elastic limit for the material, and plastic flow takes place.

A good deal of misunderstanding exists as to where the plastic range of stress begins. It needs to be emphasised, therefore, that the plastic range does not necessarily begin at the point where the stress-strain curve ceases to be straight, i.e., at the proportionality limit. It does necessarily begin at the point where permanent set first appears—at the elastic limit and where plastic flow commences. Therefore the problems that arise from the fact that a material may be stressed up to points lying on the curved portion of the stress-strain curve, where Hooke's Law does not hold good, are not necessarily problems concerned with the plastic range of stress, since, as already explained, part of the curved portion generally falls within the elastic range. They are problems connected with departure from proportionality rather than departure from elasticity; hence the reference in the title of this article to the "curvilinear range" as distinct from the "plastic

points below the elastic limit do not produce any substantial change in the shape of the stress-strain curve, although there is often evidence of some increase in proportional limit and reduction in the width of the hysteresis loop.

On loading slightly beyond the elastic limit, the shape of the hysteresis loop is little changed, but now the final point at zero load does not correspond with the initial point, a certain amount of permanent deformation, called "permanent set," occurring. Stresses producing definite amounts of permanent set are in this country called "proof" stresses; for example, that producing a permanent set of 0.1% of the standard gauge length is called the 0.1% proof stress. (It might be mentioned here that the much-used "off-set" method of determining proof stress from the stress-strain curve is only an approximation and for some non-ferrous alloys may give proof stress figures from 10 to 15% too low. Fig. 2.)

Subsequent loadings to the same point beyond the elastic limit do not produce the same permanent set on each loading as occurred on the first loading, owing to the crystallographic "slip"—which takes place after the elastic limit is passed—strengthening the material against further slip. The slip decreases with each loading and on some materials no further permanent set is produced after, say, six loadings to the 0.1% proof stress, the material then continuing to behave elastically on further repeated stressings to this figure; that is, the original 0.1% proof stress becomes a new elastic

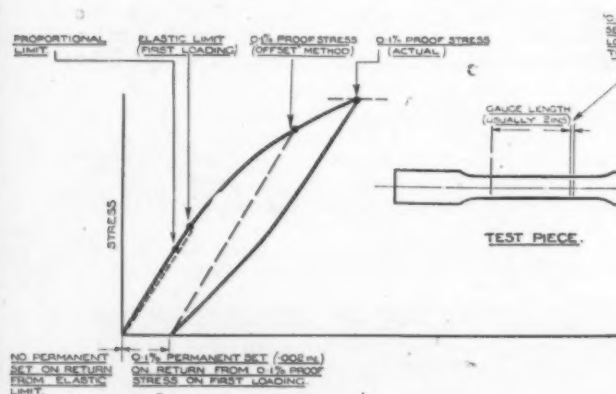


Fig. 2.—Elastic limit and proof stress.

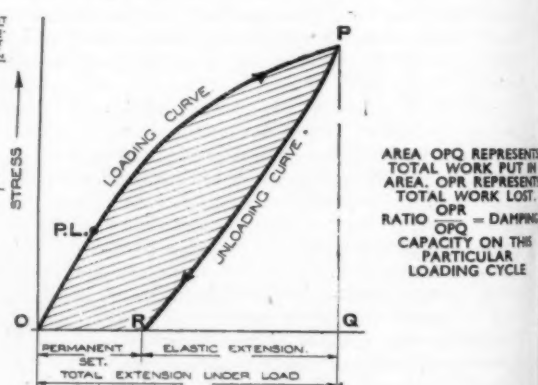


Fig. 3.—Stress-strain curve for one loading cycle.

range." Certainly the latter term is the one which has been mostly used in discussions on this group of problems up to the present, but it does not differentiate the two conditions sufficiently and is thus sometimes misleading in the point at issue.

When a tensile test bar has been loaded to a point between the limit of proportionality and the elastic limit, and the load is then gradually removed, the downward stress-strain curve traced on returning does not correspond with the "upward" curve traced during loading, although the final point at zero load corresponds with the starting point at zero load. Instead, a new reverse curve is traced, as shown in Figs. 3 and 4, which, together with the upward curve traced during loading, makes a loop called the "hysteresis loop." The area of this loop represents work lost in internal friction in the material and is a measure of the damping capacity for that particular loading cycle. Repeated loadings to

limit. For this reason, where elastic deflection under service loads is a more important consideration than the permanent set produced on the first few loadings, the 0.1% proof stress can be considered as the elastic limit, provided the secant modulus of elasticity value be used in the calculations. The 0.1% secant modulus is that which corresponds to the straight line drawn through the origin of the stress-strain curve and intersecting the curve at the level of the 0.1% proof stress, Fig. 2. For any material having a curved stress-strain curve, the secant modulus should be used in deflection calculations.

Fig. 4 shows the hysteresis loops obtained on a magnesium alloy (Elektron A.8, "as cast") on five loadings to the 0.1% proof stress. It will be seen that on the first loading cycle a permanent set of 0.1% of the gauge length occurred, but on the fifth loading cycle no permanent set could be detected by the extensometer

used, which read to 0.00005 in. Thus with this material it can be said that on the sixth and subsequent loadings the deformation is elastic; the stress-strain graph, however, is pronouncedly curved. The new developments in design methods are concerned with this

methods would be adequately dealing with stresses in this range.

Actually this is not the case; although stresses beyond the proportional limit are allowed—even standardised—present design formulae are based on the assumption that the stress distribution (not magnitude) in bending and torsion members is as if the proportional limit were not exceeded,—i.e., that the distribution gradient over the cross sectional area is rectilinear, not curvilinear. This results in a higher

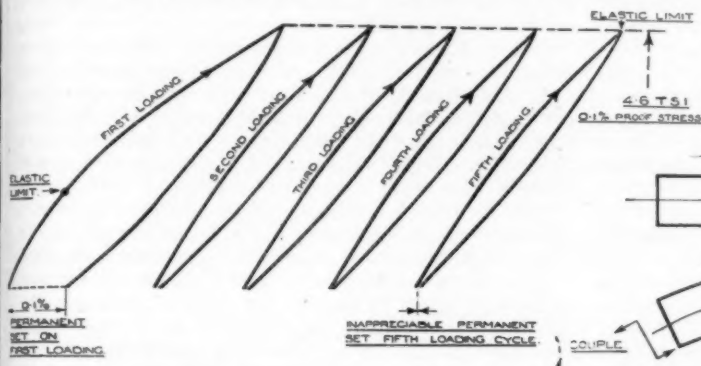


Fig. 4.—Hysteresis curve obtained on Elektron A 8 (as cast).

important feature, which, of course, is not peculiar to, although it is most pronounced in, magnesium alloys.

Proof Stress Basis of Design

It is standard practice in aircraft design to-day to allow for possible loading on the material (proof load) not only beyond the proportional limit but also beyond the original elastic limit (i.e., the elastic limit as obtained on the first loading cycle). The figure selected for the maximum limit of stress is usually that which would produce—on a tensile test bar—a permanent set of 0.1% of the gauge length (again, on the first loading cycle). It will be seen, therefore, by reference to Fig. 5, which

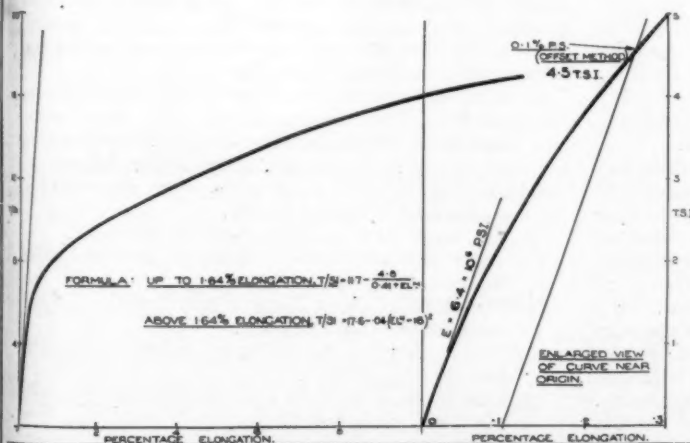


Fig. 5.—Stress-strain curve for Elektron A 8 solution treated.

is a stress-strain curve for solution-treated Elektron A.8 and typical for certain aircraft materials, that in present day practice, loading may occur beyond the proportional range and well into the curvilinear range of stress. One would expect, in view of the present state of aircraft development and accomplishment, that design

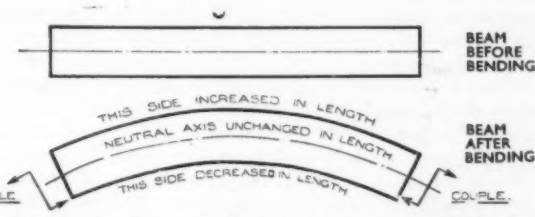


Fig. 6.—Beam in simple bending.

safety factor being obtained than nominally exists. It will be obvious immediately that possibly some advantage in design and performance might be gained if account could be taken of this difference between assumption and reality in the matter of stress distribution. As present design formulae are derived from considerations of perfect elasticity and strict proportionality between stress and strain, new formulae would be required. It is, therefore, one of the main objects of investigators in this field to develop improved methods and formulae which are more applicable for use with materials having non-rectilinear stress-strain characteristics than the present formulae.

In this, of course, much more is involved than is implied in the mere concept of making some dimensional allowance for the small original permanent set produced by working to the 0.1% proof stress. As previously emphasised, so far as stress-strain curvature is concerned, plasticity is not the problem, non-proportionality is the problem. If plasticity alone were the problem, it might appear that the new modifications in design methods would be applicable to simple tension members, which are subject to the same 0.1% proof stress design basis requirements. This type of component, however, is ruled out of the class to which curvilinear-range modifications may be applied, for reasons which will be made clear.

The Scope of "Curvilinear" Methods

Actually the advantages to be derived from the application of methods of curvilinear stress-range design are limited to those members in which the system of stressing is such that a non-uniform distribution exists. The typical cases are bending and torsion; in both of these the stresses increase from zero at the centre of the section concerned, to a maximum at the outer fibres. In a simple tension member of uniform cross-section, the stress is nominally uniform over that cross-section, and with this distribution there can be no "unloading"

from more highly to less highly stressed areas when the stresses exceed the proportional limit, or the elastic limit.

In bending and torsion members, the more highly stressed fibres on the outer parts of the section will, as soon as the proportional limit is passed at those places, begin to accept a less proportion of the total load than they did while the loading was still within the proportional limit. This follows naturally from the changing ratio of stress to strain with departure from rectilinearity in the stress-strain curve. As a result, the stress distribution over the cross-section changes from one of uniform increase from centre to outside (according to the straight line law) to one corresponding to the curve of the stress-strain relationship for the particular material.

Brittle materials like glass have practically no plastic range, the material is substantially elastic right up to the point of fracture and the permanent set after fracture is inappreciable. In such materials the complete stress-strain curve is almost a straight line and no very significant error should be introduced by the assumption that under bending, the stress distribution gradient vertically across a beam section is rectilinear. One would not expect any advantage to be gained by attempting to apply curvilinear-range design analysis to materials having these characteristics.

Further, as no permanent set is produced, the proof stress basis of design, by definition, could not be used at all. This is not to say that actual tests will not show substantial differences—on the safe side—between actual and theoretical results; the cause of these must be sought elsewhere than in stress-strain curvature, however.

In slightly less brittle materials like cast iron and hardened steel, where the stress-strain curve has a considerable proportion of the length slightly departing from the straight line, there is evidence that some beneficial effect can be obtained. How much of this is due to curvilinearity and how much to other things is not yet known.

In certain ductile materials, amongst which may be classed magnesium alloys, the proportional limit is reached, and passed, a considerable time before the 0.1% proof stress point. This is the class of material definitely amenable to curvilinear-stress-range treatment.

The standard methods and formulæ for beam and shaft design-bending and torsional stressing respectively—which were developed about two hundred, and established in their present form about one hundred years ago, are all based on the assumption of a uniform or straight line stress distribution from zero at the centre of the section to maximum at the outer fibres. This assumption was no doubt made and adopted for the sake of simplicity, for it was realised quite early in the development of bending and torsion theory that with any material having a curvilinear stress-strain relationship, the actual stress distribution in bending and torsion members when stressed beyond the proportional limit in the outer fibres would be somewhat different from the nominal straight line distribution. As the final effect, however, was apparently equivalent to a slight increase in factor of safety, (the maximum fibre stress being reduced by the "unloading" effort), the difference was, no doubt, thought of insufficient importance to be allowed for in the calculations. In those days, design requirements in the matter of weight-saving were a much less important feature than at the present time,

and a small, though unknown and variable addition to the factor of safety would on the whole be considered an advantage rather than a disadvantage, even though some extra weight were entailed. Presumably also this view has carried weight when attention has been called to the discrepancy at different times during the last hundred years or so.

Now that much more is known of the various factors involved in stress problems, particularly on the materials side, and methods of stress analysis have been further developed, definite allowances for the operation of these factors can be made in the calculations, and the nominal "factor of safety" values can be, and have been, much reduced, in accordance with the necessity for less unscientific control. Actual safety margins, however, probably remain at least as great as before, or perhaps it would be better to say, are under more accurate control.

The whole trend of the development of aircraft structural design is in the direction of reducing the numbers and magnitude of the "unknowns" and towards more and more accurate determinations of the actual stresses existing under any given loading system. The new moves in the direction of improved design methods in the curvilinear range of stress are part of this trend.

Having now given a general indication of the basic idea, it is perhaps convenient to go into further detail.

Bending Theory and its Assumptions

When a straight and parallel bar is subjected to either pure or ordinary bending, a tensile stress is produced on the convex side of the bar—on which an increase in length occurs—and a compression stress on the concave side, which suffers a decrease in length, Fig. 6. The increase and the decrease in length are both clearly maximum at the outer fibres of the bar and being opposite in direction must produce a zero change in length at some intermediate position. The line of zero change in length is known as the neutral axis; on symmetrical sections of material having elastic moduli equal in tension and compression, it occurs at about the centre of the section.

In order to obtain a reasonably simple analysis and formulation of the stress magnitudes and distribution in a beam under simple bending, it has been customary to make certain assumptions; these are as follows:—

- (1) The loading is simple bending (pure end couples) and shearing force is absent.
- (2) The material is homogeneous and isotropic.
- (3) There are no initial stresses in the unloaded member.
- (4) The material obeys Hooke's Law and the proportional limit is not exceeded.
- (5) The modulus of elasticity in tension is equal to that in compression.
- (6) The beam is straight and of uniform and symmetrical cross section.
- (7) Transverse sections (originally plane) remain plane and normal to the longitudinal fibres of the beam after bending.
- (8) All horizontal layers of fibres are free to expand or contract laterally, as if unattached to the neighbouring layers.
- (9) All horizontal layers of fibres are free to expand or contract longitudinally, as if unattached to the neighbouring layers.
- (10) All loads are applied gradually.

Of these, assumption 7 is particularly important for stress distribution considerations and is one which can easily be accepted at first sight as reasonable, particularly if a case like Fig. 7 is visualised, where a bar of symmetrical section with ends plane and parallel before bending is elastically bent into a circle; one would—with a homogeneous material having elastic moduli equal in tension and compression—normally expect the ends to come flush when the circle was completely formed.

Now if sections plane before bending remain plane after bending, then changes in length, measured parallel to the neutral axis, vary uniformly according to the distances from the neutral axis. This obviously means that a straight line distribution of strain exists from the neutral axis to the outer fibres. It follows that the actual distribution of stress from the neutral axis to the outer fibres will be given by the stress-strain curve for the material concerned, because the stress-strain curve is

not directly in proportion to y , the distance from the neutral axis, but in proportion to some function of y which gives values corresponding to the actual proportion of stress to strain over the range of stress concerned. That is, an equation must be found for the actual (curved) stress-strain relationship to replace the equation $y = ax$ (where y is stress and x is strain) which is, of course, the straight-line relationship (Hooke's Law) assumed in the standard beam formula, Fig. 9a.

Several suggestions have been made for such an expression. Beilschmidt's suggestion⁵ is to substitute $y = ax^n$ in place of $y = ax$, and he has worked out and tabulated a series of values or constants which he calls "form factors," enabling the stresses to be obtained on this basis, with a minimum of labour, for most standard section types. The correspondence between the curve given by $y = ax^n$ and usual forms of stress-strain curves is reasonably near to most practical requirements and

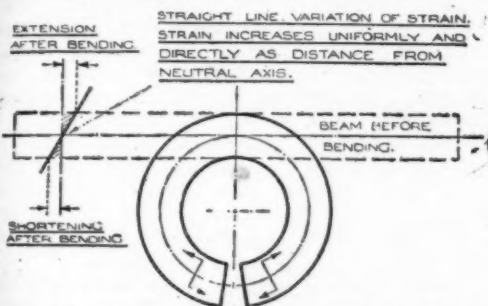


Fig. 7.—Simple bending of beam into circular form.

plotted on linear scale co-ordinates; the distribution gradient will be rectilinear (uniformly varying) if the stress-strain curve is rectilinear, and curvilinear (non-uniformly varying) if the stress-strain is curvilinear, Fig. 8.

The standard beam formula, based on the above assumptions (and thus strictly applicable only to cases of pure bending although much used for cases of ordinary bending, i.e., where shearing force exists) is expressed as follows:—

$$\frac{M}{I} = \frac{f}{y} = \frac{E}{R} \quad \text{or} \quad M = \frac{f}{y} \times I$$

where M = External bending moment, I = moment of inertia of section, f = stress at outer fibres, E = modulus of elasticity, R = radius of curvature of beam under load.

This formula contains the term $\frac{f}{y}$ and

thus states implicitly that (within the above assumptions) the stress always varies directly, or rectilinearly, with the distance from the neutral axis. It is, therefore, really incompatible with the conditions existing in any beam made from material having a curvilinear stress-strain relationship if the stress at any point reaches a figure beyond the proportional limit, i.e., beyond the end of the straight portion of the stress-strain curve.

Formula Modification for Curvilinear Basis

To avoid this incompatibility and make the formula applicable under the required conditions, the expression $\frac{f}{y}$ must be replaced by one in which the stress f varies

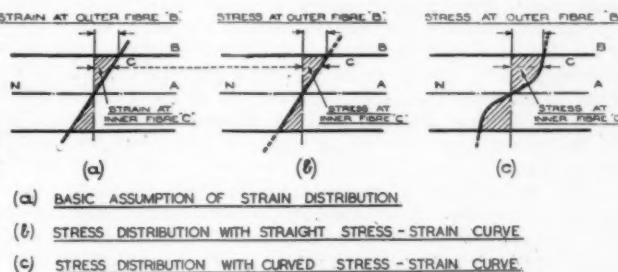


Fig. 8.—Basis for derivation of beam formula.

the use of his approximation, when stresses do not exceed the 0.1% proof stress, removes a good deal of the discrepancy introduced in the manner described above. The closeness of the approximation depends largely on the value chosen for n , Fig. 9b.

It may be desirable, however, in some cases to use a formula which gives a curve more nearly approximating to the stress-strain curve right from the origin. This $y = ax^n$ formula gives a curve having a slope of "infinity" at the origin, corresponding to a modulus of elasticity of "infinity." A curve suggested to the writer by Mr. D. B. Winter⁶ is based on "sinh" values and accurately corresponds to many strain-stress curves for the greater part of the distance to the proof stress point, Fig. 9c.

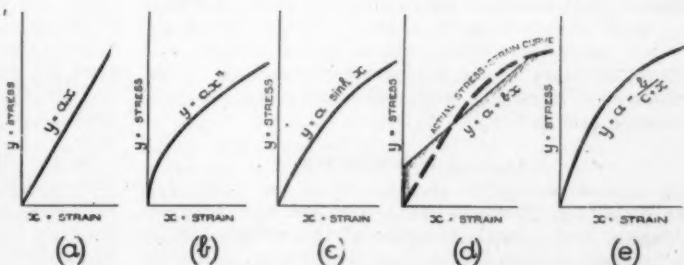


Fig. 9.—Approximation formulae for stress-strain curves.

The advantage of Beilschmidt's formula is that it is reasonably amenable to such mathematics as most engineers and metallurgists possess. More accurate formulae are difficult to deal with in the integrations.

Another type of approximation has been suggested by F. P. Cozzone.⁶ In this the conventional rectilinear distribution of stress has been replaced by a simple trapezoidal distribution. Here again the closeness of the approximation depends on the values selected for the trapezoidal proportions, Fig. 9d. The approximation shown in Fig. 9e has been found useful by the writer in constructing accurate stress-strain curves for magnesium alloys.

The "New" Ideas

It will be noted that reference has been made to "new" ideas concerned in this move towards "curvilinear" stress-range methods. However, the basic principles were realised at least a hundred years ago, and in this historical connection the following extract from the "Cambridge and Dublin Mathematical Journal" for Nov., 1848¹, is interesting. It is by Prof. J. Thomson and refers to torsional stressing in the plastic range, but the same general principle is involved.

"Let, for instance, a cylindrical bar of malleable iron or a piece of iron wire be made red hot, and then be allowed to cool. Its particles may now be regarded as being all completely relaxed. Let next one end of the bar be fixed, and the other be made to revolve by torsion till the particles at the circumference of the bar are strained to the utmost extent of which they can admit without undergoing a permanent alteration in their mutual connection. In this condition equal elements of the cross section of the bar afford resistances proportional to the distances of the elements from the centre of the bar, since the particles are displaced from their positions of relaxation through spaces which are proportional to the distances of the particles from the centre. The couple which the bar now resists, and which is equal to the sum of the couples due to the resistances of all the elements of the section, is that which is commonly assumed as the measure of the strength of the bar . . .

The twisting of the bar, however, may be carried still further, and during the progress of this process the outer particles will yield in virtue of their ductility, those towards the interior assuming successively the condition of greatest tension; until, when the twisting has been sufficiently continued, all the particles in the section except those quite close to the centre will have been brought to afford their utmost resistance. Hence, if we suppose that no change in the hardness of the substance composing the material has resulted from the sliding of the particles past one another and that, therefore, all small elements of the section of the bar afford the same resistance, no matter what their distances from the centre may be, it is easy to prove that the total resistance of the bar is now $\frac{4}{3}$ of what it was in the former case . . ."

This obviously shows a clear understanding of the "unloading" factor at work, although it applies here to torsion and to the plastic range.

Range of Discrepancy

In case it should be thought, from the value $\frac{4}{3}$ mentioned by Thomson, that discrepancies between calculated and actual strengths of the order of 33% are normally incurred under service stresses, it should be made clear that in actual practice—designing to a calculated maximum of 0.1% proof stress—the discrepancies introduced by working to a rectilinear instead of the curvilinear basis within the elastic range are usually very much less than this, say of the order of 6 to 10% only. This can be seen by reference to the

Beilshmidt form factor values, using appropriate values of n . Thus, if the calculated stress when using the straight line distribution law is normally 10 tons per sq. in., the actual figure, allowing for curvilinear distribution, would be of the order of 9 to 9.4 tons per sq. in. The maximum theoretical differences of 33% reduction in bending and 25% in torsion stress mentioned by Thomson allow for plastic "unloading" to the extent of completely equalising the stress over the section and could only be obtained elastically with a rectangular-shaped stress-strain curve unless some entirely different and additional factor is operating.

Nevertheless, in actual bending tests it is found that the discrepancies between calculated and measured figures may range considerably higher than 10% even in elastic bending. In Beilshmidt's paper already quoted, figures are given showing that in a bending test on a magnesium alloy tube the material of which had properties conforming with D.T.D.289 (0.1% proof stress $4\frac{1}{2}$ –5 tons per sq. in., ultimate stress 13–16 tons per sq. in.) no noticeable permanent set was produced when a calculated stress of 14–17 tons per sq. in. was imposed, while 28 tons per sq. in. did not produce ultimate failure.

The apparent increase in strength here is clearly of the order of two hundred per cent. rather than ten, and is thus not to be explained alone by the departure from rectilinearity in the stress-strain curve. There are obviously other influences at work not yet fully explained or understood.

If E , the modulus of elasticity, be calculated from the deflections and loads on beams tested in, say, pure bending, and using the standard formula, it will in most cases be found higher than the actual figures obtained from a tensile test on the same material.

As examples of this, the following figures may be quoted:—A round steel bar 0.75 in. diameter, was tested in pure bending and found to have an apparent modulus of 31.6×10^6 P.S.I. against 29.6×10^6 when tested in tension. The material was not strained beyond the proportional limit and thus no stress-strain curvature interfered.

A flat steel bar 3 in. wide by 0.25 in. thick was tested, again in pure bending, but here no increase whatever was found in E .

A square magnesium alloy bar (Elektron A.8, solution-treated) tested in pure bending, showed an increase in E of 17%, and a tube section of the same material 1.50 in. diameter by 1.00 in. bore, showed an increase of 50% in both E and proportional limit, but a flat bar (Elektron AM.503) 3 in. wide by 0.25 in. thick, showed an increase of only 13.6%. Stresses on the magnesium alloy bars were not allowed to exceed the proportional limit in obtaining E , therefore, no part of the increase could in any case have been due to stress-strain curvature.

In Sir Alex. Kennedy's experiments² (reviewed by Muir and Binnie) a beam $1\frac{1}{2}$ in. deep by $\frac{3}{4}$ in. wide was tested in pure bending and the modulus of elasticity found to be 33.3×10^6 against 29.6×10^6 when tested in tension. Muir and Binnie³, however, tested a beam 0.25 in. deep by 0.34 in. wide in pure bending and found no difference in E from that obtained in a tensile test. They state that Kennedy's results are difficult to account for except by some fault in the bending experiments. It will be noted, however, that all the results quoted above point in the same direction, viz., that the

beam with the higher ratio of depth to width gives the higher E. This is probably connected in some way with the curvature of the beam in a transverse direction (the anticlastic curvature) which varies with the varying ratio of depth to width.

There are many factors to which consideration might be given in an investigation into these additional discrepancies, for example, (a) the validity of assumptions Nos. (8) and (9); (b) the effect of deflection due to shear forces in ordinary bending; (c) neutral axis shift; (d) constancy of Poisson's ratio; (e) varying ratio of anticlastic curvature; (f) generation of triple tensile stresses.

In conclusion, it is not intended to enter into any discussion of these further points in this article, it is considered that sufficient has been said to show that the

unsolved problems connected with bending may be many, and that a pressing need exists for both practical and theoretical investigation to attempt to provide answers to these problems.

REFERENCES.

- 1 Cambridge and Dublin Mathematical Journal, Nov., 1848. Extract reprinted in "Papers in Physics and Engineering," Prof. J. Thomson, 1912.
- 2 Sir Alex. B. W. Kennedy. *Engineering*, June 15, 1923.
- 3 Prof. J. Muir and D. Binnie. "The Overstraining of Steel by Bending." *Engineering*, Dec. 17, 1926.
- 4 Baker and Roderick. "Plastic Theory and Its Application to Design." *Trans. N.E. Coast Inst. Engrs. and Shipbuilders*, 1940.
- 5 Beilshmidt, J. L. "Stresses Developed in Sections Subjected to Bending Moment." *Proc. Roy. Aero. Soc.*, July, 1942.
- 6 Cozzone, F. P. "Bending Strength in the Plastic Range." *J. Aero. Sciences*, May, 1943.
- 7 Beilshmidt, J. L. "Strength of Light Alloy Components." *Aircraft Engineering*, March, 1944.
- 8 D. B. Winter. Private Communication, 1943.

Beryllium-Copper

Some of Its Properties and Applications

Beryllium-copper is not a new alloy: it has been applied for some years in Germany and the United States, but, before the war, little interest was taken in its development and application in Britain, probably because production processes were covered by patents in Germany and the United States and supplies for use in this country required to be imported. A contributing factor to this lack of interest was probably due to the variable quality of supplies then obtained from Germany, which earned for the alloy a bad reputation. Since the early days of the war the Telegraph Construction and Maintenance Co. have manufactured this alloy for those special purposes where no other material would readily serve and as supplies of raw material become easier, usage will greatly increase because its properties are of an outstanding character. Mr. W. F. Randall, of Telegraph Construction and Maintenance Co., Ltd., and Mr. E. M. Foster, Beryllium and Copper Alloys Ltd., discuss some of the characteristics and properties of a beryllium copper alloy, known as Cu. B. 250.

JUST as the last war stimulated the production of various ferrous and non-ferrous alloys, so in this war considerable work has been carried out on what can be termed the newer alloys. Amongst those which have found increasing use in this war are, beryllium-copper alloys and, in view of their outstanding properties, there are prospects of their greatly increased application under peace conditions.

Processes for the extraction of beryllium were developed in Germany and in the United States and its use as an alloy with copper has, for some years, been regarded as an extremely important development in those countries—indeed a dramatised account of its importance is given in the publication—"Germany's Master Plan." Before the present war, beryllium alloys did not arouse much interest in Britain and an endeavour was made by German interests to include United States manufacturers in a scheme of world control of manufacture and allocation of markets. In this scheme, supplies to this country were restricted to German manufacturers.

The extended use of copper, hardened by beryllium, is primarily dependent upon the economical extraction of beryllium metal from its ore in a form suitable for alloying. The source of the metal is beryl, which, in its purest and finest form, is a semi-precious stone. The

ore does not occur in this country although ample supplies are found in India, South Africa and Canada. Beryl is also obtained in South America which could be shipped to this country at practically the same cost as to the United States where both Indian and South American beryl is used.

The extraction processes are well covered by patents and are not carried out in this country and since the most suitable form for alloying copper to produce the commercial beryllium-copper alloys was found to be by means of a cupro or master alloy containing 4 to 5% beryllium this country is also dependent on foreign countries for supplies of master alloys. With supplies of master alloy however several types of beryllium-copper alloys can be made but the particular alloy to which attention is directed is that containing 2 to 2.5% beryllium. Supplies of master alloy received in this country before the war were so variable in quality and characteristics that 2% beryllium copper acquired a bad reputation.

In the first month of the present war the Telegraph Construction and Maintenance Company appreciating the need for uniform quality of beryllium-copper embarked on its manufacture but owing to restriction of supplies the alloy was devoted only to those special purposes where no other material would readily serve.

Now that conditions are easier it is anticipated that additional supplies will become available to extend its applications.

The manufacture of 2% beryllium-copper which the above company has designated "Cu. B. 250" demands full resources of metallurgical control methods and is now supplied in most forms with fully reproducible and consistent tensile and elastic properties.

Physical Properties

As is well known copper is a soft metal and except for cold working and alloying it is not capable of being appreciably hardened. Of the hardening alloys used none approach beryllium in efficiency. Even the usual hard copper alloys such as phosphor bronze, nickel silver, or hard brass, depend to some extent for their hardness upon working the material, and this fact restricts the forms in which these alloys can be used apart from the fact that the hardness so produced rarely exceeds 250 Brinell. On the other hand beryllium is so potent that soft copper acquires a hardness of 400 Brinell when 2% of beryllium is added to it and the material is properly heat-treated. Thus, an alloy is produced which is basically copper, with all its advantages, and yet has the hardness of a reasonably good carbon steel. It provides high conductivity, non-rusting qualities, lower rate of atmospheric corrosion, non-magnetic quality—all properties which cannot be obtained from steel. The alloy may be obtained in either the soft, cold-worked or hard conditions; the soft material is fully malleable and ductile, and can be rolled or drawn to wire, pressed or worked almost as soft copper. Subsequently, these worked parts, by heat-treatment at 300° C., can be hardened with little distortion or oxidation, so that quite close limits can be adhered to.

There has always been a demand for a metal with high electric conductivity, high tensile and fatigue strength in the production of particular electrical equipment. The alloy Cu.Be.250 answers all these requirements. Electrical conductivity is very high for an alloy of such strength and is equal to about 30% that of pure copper. It is a good conductor of heat and superior to that of steel of equivalent strength. In the fully hardened condition it gives up to 400 Brinell, so that its resistance to abrasion when used in wearing parts is extremely high. When running against steel, the alloy shows a low frictional loss and it can be used to advantage where rubbing contact with steel occurs. The fatigue strength—resistance to alternating and vibratory stresses—is higher than that of any other known non-ferrous alloy, and approaches that of hard steel. Under corrosive conditions, the fatigue strength of steel diminishes rapidly and under such conditions beryllium-copper will give greater strength. The alloy has an extremely high tensile strength for a non-ferrous material. This runs as high as 90 tons per sq. in. with a proportionately high yield point—equivalent to a good quality hardened steel.

Some Applications

In a brief reference to suitable applications for this alloy, two fields may be discerned, namely, applications for working instruments or machine parts such as springs and diaphragms, and applications as non-magnetic and non-sparking safety tools. It might be usefully employed for switch gear parts in the electrical

power industry such as contact springs, make-and-break contacts and current-carrying parts with or without high conductivity plating or contact studs.

The radio industry offers scope for parts like valve clips or other intricately shaped springs, because this alloy can be formed and shaped while soft and made strong afterwards by a relatively low temperature heat-treatment. Measuring instruments, whether they measure in the air, on land, or under the sea, could profitably use the alloy for pressure diaphragms, for thermostatic control valves, pressure tubing, or certain other instrument springs, and for springs controlling the accuracy and service of meters. In electrical transport the alloy will be found useful for signalling equipment for certain overhead equipment where resistance to abrasion and to corrosion by atmospheres—either industrial or those influenced by the nearness of the sea—is of importance. It could be profitably used on the instrument panels of oil- or petrol-driven motor transport vehicles, since the effect of vibration or long service would be almost negligible. Engineering in general would find the alloy useful in all cases where a non-ferrous metal of high tensile strength and particularly high resistance to fatigue is required.

Even spring steel could in many instances be replaced as a spring material, as for instance in tropical countries where the peculiar atmospheric conditions are not very healthy for ferrous materials. The alloy would also be useful for a welding jig where high strength and hardness proved more important than electrical conductivity, or the instrument maker might use it for non-magnetic spanners or pincers for minute washers or screws.

This alloy has non-pyrophoric properties in common with other copper alloys, and this quite naturally leads to its use for sparkless safety hand tools for explosive chemicals, for petrol and paint, for cellulose and other highly volatile solvents, for gas works as well, and in short, for all such conditions where sparks into an explosive atmosphere might cause fire and explosions. All industries using cellulose spraying for aircraft frames, car bodies, transformer stampings, to mention only few would find beryllium-copper tools to be hard wearing and safe; gasworks too, for clearing out their purifiers, and builders who have to deal with petrol-soaked concrete. Hammers, spanners, scrapers, chisels, even saws for the cutting of cordite sticks would give excellent service and long life.

It should not be assumed from this brief review of the properties and applications of beryllium-copper alloy that no problems will be encountered in its use. Like any other material it has limitations. It should be noted, for instance, that the alloy is a low-temperature hardening material and the maximum service temperature should not exceed about 200° C. Another difficulty is that during the heating for heat-treatment the material is softened at first, therefore weak springs whose shapes do not provide sufficient reinforcement should be supported and clamped during the heat-treatment operation. A further point which designers must watch, particularly in the case of electrical contacts, is that during service a thin film of beryllium oxide forms very quickly under exposure to air, which, whilst not affecting the tensile strength and hardness, as this thin film prevents further oxidation, would affect the electrical surface conductivity and steps have therefore to be taken to counteract this where they are required.

The Coinage Metals in Antiquity

Part III.—Asia Minor, Phœnicia and South Russia

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This part continues the author's critical review of metal extraction and craftsmanship, since the third millennium B.C., of Phœnicia and deals with metalliferous mining in Spain, silver and other metals; scripts; Phœnician metallurgy, bronze, ras shamra, byblos and includes a consideration of the vigorous metal culture of South Russia.

Metalliferous Mining in Spain

Silver.—Their most important mining settlement was in Southern Spain, Andalusia, equated with the Tharshish of the Old Testament; their towns included Gades or Gadir (the enclosed place), modern Cadiz, on the Atlantic, and Carthago Nova, modern Cartagena, on the Mediterranean. From these deposits they exported enormous quantities of gold, silver, copper and cinnabar to the eastern Mediterranean, and this trade persisted long after their empire had decayed. All the Greek and Roman historians were fascinated by the mineral riches of Keltiberia. For example, DIODORUS remarks on the most abundant and best known sources of silver, and to the workers of silver it yields large revenues. . . . Now the natives were ignorant of the use of silver and the Phœnicians, as they pursued their commercial enterprises and learned what had occurred, bought the silver for other wares of little if any value. So far did the merchants go in their greed that, in case their boats were fully loaded and there still remained a great amount of silver, they would hammer the lead from the anchors and make the silver replace the lead (5, Chap. 37). Too good navigators to risk overloading, they adopted this ingenious artifice to increase the profitable cargo.

About the beginning of the Christian era, the historians PLINY, STRABO and DIODORUS all esteemed Iberian silver very highly. As this was known to contain a few per cent. gold, some commentators have assumed that the technology of that time did not permit separation of the gold, since its greater value (13 or 10 times that of silver) was very well appreciated. DIODORUS, quoting AGATHARCHIDES of the third century B.C., in his description of gold-mining in Nubia, gives a reasonable description of cupellation: *Then finally other craftsmen take what has been recovered and put it in fixed proportions into earthenpots, mixing it with a lump of lead proportionate to the mass, lumps of salt and a little tin, and adding barley sharps to it. Then they put a close fitting lid on it and luting it carefully with clay, bake it in a furnace for five days and nights in succession; and at the expiration of this time, when they have allowed the pots to cool, they find no trace of other matter in them, but the gold they recover in a pure state.* Moreover, as has been shown, the Babylonian craftsmen were able to carry out rough quantitative fire assays at least, by 1500 B.C. Cupellation will not separate silver from gold, and fusion with common salt only imperfectly and ineffectively as molten silver chloride, which is slagged off. It is hardly conceivable that with their poor technology, much inferior to the Egyptians', Hittites' and Iraki's, eastern Mediterranean peoples should be acquainted by wet parting by nitric acid or

dilute aqua regia. Perhaps, therefore, the conclusion is justified.

Other Metals.—Among the earlier historians—DEMETRIUS, POSEIDONIUS, ATHANAEUS—Spain was celebrated, perhaps by exaggerated repute, for gold no less than silver. . . . in Iberia the river called Theodoros silts up quantities of gold at its mouth—DE MIRABILIBUS, attributed to the peripatetic school of ARISTOTLE. DIODORUS wrote: *Opening shafts in a number of places and digging deep into the ground, these men seek out the seams of rock rich in silver and gold; and not only do they go a great distance into the ground, but they also push their diggings many furlongs deep, and drive galleries at every angle, turning this way and that.* The same vast ore body is being worked to-day for pyritic copper, levels having been driven at ever increasing depths, from terraces. Where old workings, attributed to the Romans, but perhaps even older, are encountered, they invariably follow the veins without any attempt at systematic exploitation or prospecting. Intrusive volcanic dykes were countered by tunnelling, confirming very accurately the historical record written two thousand years ago.

An interesting museum of old relics has been formed, including stone hammers and bronze tools, inscriptions in Latin, several of the water-wheels used to drive Archimedes screws for pumping, and even a screw itself as described by DIODORUS and depicted on an ancient stone carving. By the time the Archimedes screw was in use the Phœnician Empire has disappeared as an entity, and its enterprise had fallen into possession of its colony, Carthage, and the grasping Roman Empire.

Gold was obtained mainly from placers, also by washing crushed rich lodes, the silver chiefly from vein ore. The outputs obtained appear large, especially in view of the absence of mechanical handling, but for the enormous slave gangs employed, they are relatively meagre. Strangely enough, we have no historical record of copper-winning in ancient Spain, and metallic mercury does not seem to have been exported before the Christian era. Labour conditions were incredibly bad, the miners being virtually imprisoned in the hot, foul atmosphere of the deep galleries without ever being released to the sunshine and fresh air. From methods advocated by Xenophon for the silver mines of Laurion, we see that Stakhanov tactics and Bedaux speeding-up are no new invention. A striking instance of the disregard of any human value is the shape of ancient passages still preserved in the Rio Tinto mines—large enough to pass the head and shoulders of a man, and worn smooth with continuous use.

With the departure of the Romans from Spain, mining stagnated for a millennium under Moslem

* From page 206 February Issue.

government. The old name Tartessos survives in the town and mine of Tharsis, and Ezekiel's stone of Tharshish has been identified with cinnabar.

As a result of flourishing Phœnician commerce, Sardinia, Crete and Cyprus became important *entrepôts*; it has already been suggested that Phœnician tin of Spanish (Artabrian) placer origin, and later of Cornish vein origin, was alloyed with Cyprian copper, perhaps in Cyprus itself. This gave the second bronze age of Irak and the bronze age of Egypt. The first bronze of Sumer, 3500–3200 B.C., died out as the supply of Lake Van bronze dried up from exhaustion of (local Persian?) tin ores. Dates are difficult to assign. In Irak the second bronze age began rather indefinitely after 2000 B.C., to reach a peak of fine work by the Assyrians at 1000–600 B.C. In the Nile Valley data are very doubtful and inconclusive. It was occasionally, though scantily, used as early as the III dynasty (*circa* 3000), this was low in tin. Even before this, tin-modified coppers like those of contemporary Sumer and Agade had been used. By the MIDDLE KINGDOM (say, 2000) it was much more common being used side by side with copper—e.g., bronze hinges on copper doors. Not until the very prosperous importing period of the EMPIRE 1580–1090 did it become really common; the tin content, too, rose higher. It is unlikely that Andalusian copper could have been available in sufficient quantity at these early dates. *Mais au début de l'histoire, quand la marine phénicienne n'existait pas encore, il faut bien admettre que l'étain dont usaient la Mésopotamie et l'Égypte, venait surtout de l'Asie par caravane et par cabotage. La question de l'origine de l'étain employé au début de l'âge de bronze reste fort obscure.*

Strangely enough, Phœnicians do not seem to have founded any settlements at the Pillars of Herakles—Algeciras, Gibraltar, or Ceuta—which would have been of immense value as nautical look-outs. Marseilles (Massilia) was formerly regarded as one of their settlements, an inscription of some importance, in their script, having been found there. More probably it was a foundation of Ionian Greeks fleeing from persecution. Punic and Phœnician elements were strong. In pre-Christian times it was as thriving a port as to-day; like Narbo, it was a terminal for the overland route for transport of Cornish tin.

Scripts—Invention of the Alphabet

*Phœnices primi, famae si creditur, ausi
Mansuram rudibus vocem signare figuris.*

*If rumour be believed, the Phœnicians were the
first who dared*

To denote the voice by rough symbols.—LUCIAN.

As shown clearly by the Tell al Amarna correspondence on clay, cuneiform was in general use in the near east in the sixteenth and fifteenth centuries B.C. Our knowledge of the Phœnician's temperament and achievements would not lead us to regard him as likely to *invent* alphabetic letters. Nevertheless, he is generally credited with the introduction of an alphabet of 22 consonants, without vowels, about 1200 B.C. Previously his medium had been the ubiquitous wedge script, and the letters were developed from Egyptian shorthand contractions of the hieratic or priestly language, a shorthand already in use as early as pre-dynastic times, 3500 B.C., according to BREASTED.

There are some close analogies between early Phœnician letters, archaic Hebrew signs, ancient Ionian and Doric letters, and the peculiar syllabic script found

in the inscriptions of Cyprus. Other sources suggested are Philistinian from Crete, the Ras Shamra tablets from the Syrian coast, cabalistic scratches in Egyptian copper mines in Sinai, the archaic lettering discovered on Thera by Hiller. The similarity of these scripts has led to the postulate of a common primitive, from which they all diverged, which has itself vanished. For instance, the script of Ahiram's tomb shows definite divergences from that of the important Mesa stela; the Punic characters developing in the daughter city of Carthage show a trend different from that in the homeland nearly 2,000 miles away. Nevertheless, it seems to the author more likely that the analogies are due to convergence of primitive scripts which coalesced to give the letters disseminated by Phœnicia in her trading missions, which finally emerged as the occidental alphabets. On this basis our present writing mechanism is a hodge-podge derived from a number of archaic scripts, not all of which are known to us. If the material available were wider and more varied it would be possible to reach more positive conclusions. For many centuries the Phœnician was content with a modification of the Sumerian cuneiform script.

Phœnician Metallurgy

Bronze.—Phœnician metal objects, chiefly bronze, show indifferent craftsmanship and poor artistic standards. Probably this is the reason why so few have survived; there would be no compunction in remelting or reforging an artefact of slight artistic worth yet of intrinsic value as scrap. Yet at the time when the Temple of Solomon was built, the artificers had a reputation for sound workmanship (989–982 B.C.). The Tyrian smith Humarabi fabricated the large pillars of the porch *Jacin* and *Boaz*, 6 ft. in diameter hollow cast in bronze 3 in. thick and 35 ft. high, though discrepancies occur in the dimensions and materials stated in the Old Testament. The "sea" was a priests' bath 15 ft. in diameter, with walls a palm breadth thick, the bronze being made from copper captured by King David in Syrian cities. Smaller portable baths or water tanks *lavars* were also made, as well as tools and temple utensils.

The Greeks had a high opinion of Phœnician plate and jewels—e.g., Homer mentions the silver craftsmanship of Sidon with admiration, doubtless this developed on account of the rich mines of Sardinia and later Andalusia. In view of their success in adopting ideas gained from subject races, a tendency to exploit the culture of constituent races skilled in metallurgy (Hittites and Philistines) would cause no surprise, and it is to these sources that the author attributes such skill in metal working as the books of the Old Testament show them to have possessed: large castings like those described would be no light undertaking even with the technical appliances available in the foundry to-day. Well designed and finished (ceremonial?) bronze razors and weapons were manufactured, but their statues and statuettes were poor productions artistically.

Ras Shamra.—On the coast of Syria opposite Salamis in Cyprus some sort of clearing-house, between Asia, Asia Minor and the Aegean islands, seems to have existed. Numerous bronze objects have been recovered—daggers, a tripod, engraved weapons, jewellery—dating from about 1400 B.C. Ingot gold and silver, and statuettes inlaid with these metals were also found. Tablets in an archaic Hebrew, or at least Semitic dialect written in cuneiform are attributed to the same date. In substance

they resemble the Mosaic books of the Old Testament (perhaps twelfth century). The script is of interest, since it shows the beginnings of an alphabet.

Byblos.—As this city was essentially an Egyptian *depôt*, one can hardly attribute to Phœnicia specimens of bronze found there. They include weapons, Mykenae-like tridents, jewels and torques ranging from 1600 to 2300 B.C. As one might expect, the styles show a variety of influences—Egyptian, Assyrian, Hittite, Susian, Caucasian.

Iron objects were also recovered, but only in small quantity.

8. SOUTH RUSSIA

The wealth and quality of metal artefacts recovered in archaeological excavation north and east of the Black Sea is not appreciated generally. Yet these constituted a magnificent collection in the Hermitage Museum of the Cæars in St. Petersburg. Excavation was first stimulated by scholarly aristocrats fleeing from the terrors of the French Revolution, who settled in a then semi-civilised country.

South-Eastern Steppes

Greek colonisation eastwards, in the valleys of the Dniepr and Donetz, in the Kuban, and far outwards into the Don basin, is widely known; their prosperous towns became centres of their rich culture and they took as great a pride as the English in maintaining islands of their own civilisation, usages, and coinage, amongst the despised indigenes. Funeral customs of the Scythians, a term applied indiscriminately by Hellas to the eastern *barbari*, was described by Herodotus, and much of his account has been substantiated. They possessed ferrous weapons and armour, and consolidated their power about the sixth century B.C.

The metal craft which has survived is almost wholly Hellenic in type though modified by local influences—e.g., the Celtic culture of the Kimmerians. As we approach Siberia, oriental influence becomes more and more obvious; so marked, indeed, that Rostovtzev has gone so far as to postulate that the animal style of South Russia was formed by an Iranian people, Sacians, in constant intercourse with Assyria. These introduced it from a region including Southern Turkestan, and the Altai Mountains rich in metals, where the tombs resemble those of the Kuban. A similar animal style is found in Thrace, and may be correlated with the same treatment in other cultures—for instance, in Ireland, Susa, and Northern Europe.

The Steppe Roadway.—In the southern steppes one nomad people had succeeded another, the significance of this area as a well-trodden roadway between Orient and Occident is fully appreciated; in primitive times, with no circumnavigation of Africa and the Horn, it was especially important. Celtic Kimmerians were displaced by Scythians, an Iranian people with Mongol characteristics; Hippocrates described them as rich in gold apparatus. In turn, these were driven westwards by the pressure of the Sarmatians, who spread outwards from a focus in Central Asia reaching the Don by about 300 B.C. Probably an Iranian race, they were fire worshippers, wore coats of iron mail, conical iron helmets, lances and swords, and had tombs like the Scythians' but more primitive. Roman provinces on the Danube fascinated them by their riches; though they never managed to occupy them permanently, their encroachments were a thorn in the flesh. In the first century A.D., during

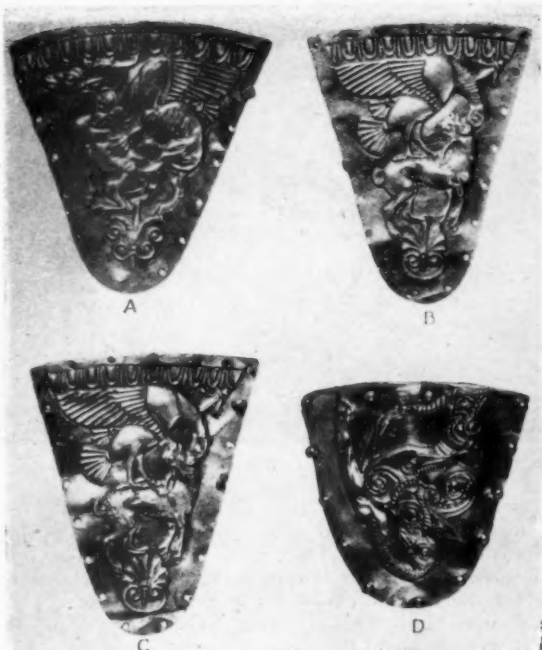


Fig. 25.—Fine beaten gold ornamental plaque, from wooden rhytons, recovered from Tumuli of the Seven Brothers, Kuban Valley, about 1875. For simplicity, dignity and economy of line, compare with proto-dynastic hammered gold work from Naga el Der, discovered by Reisner, nearly three millennia earlier. Compare also with Fig. 22, Greek style, circa fifth century, B.C.

Nero's rule, they were expelled across the Danube, but the Emperor's grandiose project of an expedition into the Caucasian steppes was abandoned on his dethronement. Subsequently the Sarmatians, allied with Thracians and Teutonic tribes, caused Rome much trouble in the Dacian wars. By the second century A.D. Teutonic graves and settlements had become common on the Dniepr. About the ninth century Norse princes (*Varanger*) established, by invitation, a hegemony of the Russian cities with capital at Kiev, and this formed the nucleus of the present state.

Hellenic-Scythian.—South Russia, therefore, in the first millennium B.C., and probably even before, was an immense melting-pot of varicous cultures, and the rich tradition developed in craftsmanship and art will cause us no surprise. In the fourth and third centuries B.C. Scythian tombs were carefully constructed on a wooden framework, and lavishly furnished with first-class works of metal-work and jewellery. Horses and oxen were frequently, and slaves occasionally sacrificed. The richest find has been in the barrow at Solokha near Nikopol on the lower Dniepr—bronze armour and copper weapons, a gold torque, plaques and bracelets, a silver-gilt quiver and copper cauldrons. Fig. 23 shows the exquisite craftsmanship in a gold comb from this burial. A silver cup of delightful lines is decorated with a combat scene in repoussé, including mounted hunters, a lion, and wolfhounds; the goblet is enriched with a border of stylised ivy-leaves at the top and with terminated fluting at the base (see Fig. 24). This find is dated at fourth century B.C.



Fig. 27—Coffee Pot Ladle.

Scythian dominion at its acme extended not only over South Russia, but well into Asia Minor, in which they were defeated by the Medes in 590 B.C. It has also been suggested that their influence culturally extended far westwards into Europe, as far as Vetttersfelde in Prussia, and even into Spain! The Keltic enclave of the Kimmerians about the strait of *Panticapaeum* (Kerch) is well known.

Kuban Valley.—In the Kuban region the components were even more mixed, and the accomplished metallurgical civilisation of Asia Minor made itself felt. This fertile district was thickly populated, and obviously had access to the metals so plentifully produced on the other side of the High Caucasus, resulting in a rich metal culture as early as the third millennium B.C. This is comparable with those of Egypt and Sumer, though about half a millennium later. "Stone-box" graves abound, the walls and the burials were painted red, also some of the ceremonial furniture; many of these graves have been found near Maikop. Crudely engraved silver vases of characteristic form from this period recall the beaten gold plaque from the Treasure of the Oxus—(Fig. 13)). In the most important grave, a composite of undressed stone, wooden walls, and floor paved with pebbles, buried 35 ft. deep under a mound in the city of Maikop, an extraordinary profusion of metal objects was discovered. These include a diadem of rosettes, statuettes of lions and horned bulls, rings and beads, all of simple and delightful workmanship in gold, no fewer than seventeen vases in gold, silver and stone. Tools and weapons in stone and copper, vases in copper and pottery were also recovered from this tomb, obviously that of a chieftain or local king; hundreds of less splendid burials have been identified. The artefacts show analogies with those from Elam, Mesopotamia and the Nile, in artistic treatment. A development can be traced from the relatively primitive animal decoration of Kuban ornament to the richer yet severe geometrical work found on Trojan objects.

Metal Craftsmanship.—It appears to the author that many characteristics of early (3000–2000) metal objects from the Kuban can be explained by the spilling over of Hittite influence across the formidable Caucasus barrier or alternatively by sea, though in view of local geography this is less likely. Despite the neighbouring producing centre near Lake Van, bronze is relatively

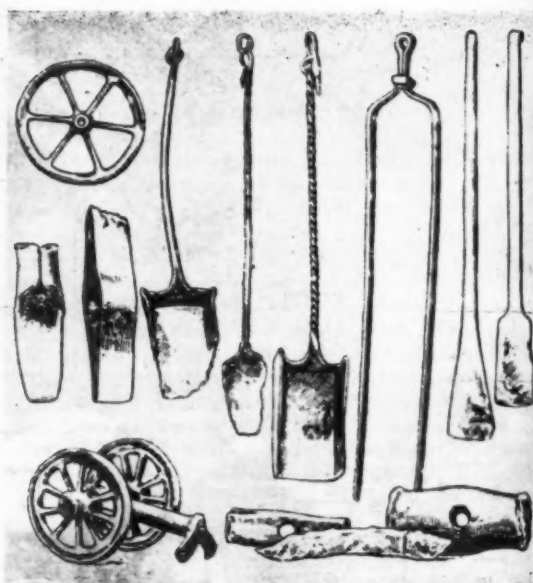


Fig. 28.—Bronze Tools from Cyprus.

scarce, though not absent—a Kuban chariot resembling the Cappadocian example in the Ashmolean Museum. It seems noteworthy that Scythian bronze artefacts from the west of Siberia show similarities in treatment, with pole tops from Cappadocia in the British Museum, in which Hittite craftsmanship may be traced; Scythian gold was no doubt derived from the Altai Mountains of Siberia.

Later, Greek influence was predominant. Fig. 25 shows fine beaten gold plaques on wooden rhytons recovered from the Tumuli of the Sveen Brothers, in 1875 *et seq.* about 20 miles from the mouth of the Kuban River. In dignity and simplicity they remind us of early dynastic work nearly three millennia older, recovered by REISNER from Naga el Der in Egypt, although the treatment is quite different. In artefacts from this grave Scythian influence is almost entirely wanting. A rhyton from these Tumuli showed a treatment similar to that in the well-known Armenian silver-gilt gryphon rhyton attributed to about the same date, fifth century B.C. (see Fig. 22).

Infra-Red Lamp Heating

A brochure has just been published by The General Electric Co., Ltd., on the subject of infra-red lamp heating. It not only describes in a comprehensive way the developments recently made in this highly efficient form of heat-treatment for many industrial processes, but also illustrates and gives technical particulars of many installations in which infra-red heating has been applied successfully. Specialists of the G.E.C., who have been largely responsible for this outstanding achievement in aiding and speeding war-time production, are available to advise, without obligation, on the best procedure to suit the needs and purposes of any firm which may be interested in the adoption of methods of heat-treatment in which speed in production and improved finish are paramount features.

Steel Foundry Practice

First Report of the Foundry Practice Sub-Committee of the Steel Castings Research Committee

Formed by the Steel Castings Research Committee in 1938 to carry out practical investigations into problems encountered in the steel foundry, the above Sub-Committee recently presented its first report. This Report is divided into six parts which include the feeding of simple castings; the "whirl-gate" head and the "atmospheric" head feeding compounds; hot tears; war-time activities; and fundamental casting problems to be considered. This important contribution to the solution of problems associated with steel foundry practice is comprehensive and can only be reviewed here with appropriate abstracts from the Report.*

WHILST many problems encountered in the production of castings are common to all types of foundries, whether ferrous or non-ferrous, different techniques usually must be employed, according to the particular metal or alloy used and frequently to suit the special design of a particular casting, in order to produce sound castings. It is probable, however, that the problems associated with the production of steel castings, because of the relatively higher temperatures and the characteristics of molten steel, are more difficult of solution. In order to assist in the development of appropriate techniques for the production of sound steel castings the Foundry Practice Sub-Committee have carried out some practical investigations into some of the problems encountered, brief reference to which is given under their respective sub-headings, while particular attention is directed to the views of the Sub-Committee on the results of the work.

The Feeding of Simple Shapes

Work on the running and rivering of simple shapes has been carried out and the results are recorded. In this investigation 4-in., 6-in. and 9-in. cube castings were used and are considered in one section, while further work was carried out on castings 6 in. square by 12 in., 18 in. and 24 in. long. The effectiveness of various types of feeder-heads normally used in steel foundries is illustrated by a large number of sawn sections of the experimental castings. The disadvantages entailed in using narrow heads, which freeze prematurely, and the advantages of wider heads, insulated heads and the use of mould material which promotes differential solidification are illustrated.

The members of the Sub-Committee realise that the experiments so far carried out cover only part of the field to be investigated before rules relating to running and feeding can be given for general application. However, the results so far obtained are, in the main, consistent and enable the Sub-Committee to make the following observations.

In making 6-in. cubes, to obtain the most economical use of the steel, the area of the bottom of the feeder head should be as large as the area of the upper surface of the casting. The Sub-Committee realise that in making commercial foundry castings a head covering the entire upper surface of a casting is seldom possible or practicable, so that horizontal feeding becomes necessary. This aspect of the problem received attention in further experiments.

Enlarging the bottom of the head, where it joins the casting gives better results, with a casting such as a cube, than constricting the head at its junction with the casting. The shape of head normally used to feed steel ingots appears to be very effective.

It is advantageous to secure a differential rate of cooling in the casting and in the head. This has been obtained:

- (1) By lining the head with a layer, $1\frac{1}{2}$ in. thick, of material having a low thermal conductivity, and thus reducing the rate of cooling in the head, and
- (2) by the use of external chills, to increase the rate of cooling in the body of the casting.

In this connection it is to be noted that the Sub-Committee have not investigated the effect of internal chills in the form of horse-nails and other metallic shapes. They consider that insulating heads can be used with advantage much more widely than at present, so long as certain practical precautions are taken; for example, it must be remembered that insulating sand mixtures are weaker than ordinary dry sand, and also that insulated heads must not be heated to such a high temperature during the drying process that the coal dust is burnt out or the sawdust charred. The use of insulating sand heads appears to be at least as efficient as the use of feeding compound.

There is some suggestion in the results that hot steel poured slowly gives less piping than cold steel poured quickly.

Most of the cubes examined were made by the basic electric-arc process. In some cases variations in feeding have been found in comparing the cubes made in different foundries. This may be connected with the degree of deoxidation of the steel concerned. A study of the steel analyses reveals that steels with a higher silicon content give deeper piping than those containing less silicon. To compare with these cubes, a number of others were made in acid converter and in acid open-hearth steels. Under the conditions of the present experiments, the steel made by both acid processes gave somewhat greater piping than basic electric-arc steel.

The Sub-Committee wish to make it plain that, in such investigations as are described above, as many conditions as possible must be made standard and easy of attainment. Some of them therefore do not correspond to actual foundry practice, in which the efficiency of feeding is not the sole aim and may not even be the first consideration. There are many types of steel castings that are regularly made in substantial quantities by different foundries where successful results are consistently obtained by methods which, whilst standardised in a particular foundry, vary considerably between one

* Paper No. 12/1945 of the Steel Castings Research Committee (submitted by the Foundry Practice Sub-Committee) and published by the Iron and Steel Institute, February, 1945. (Advance copy.)

foundry and another. This is usually due to exigencies of local equipment and conditions, and it does not follow therefore that a method successful in one foundry will be equally successful in another, where the materials available and the foundry conditions are different. Some of the factors involved in selecting practical procedure in a given foundry are very briefly mentioned below.

The orientation of the pattern in the mould is influenced by the incidence of machined surfaces, the size of mould box available, the ease with which cores may be supported, the disposition of the thicknesses which demand feeding, and so on. The orientation selected is based on a compromise between the varying demands, and to obtain efficient feeding it may be necessary, for example, to put at the top of the mould surfaces which must afterwards be machined.

The position of the ingate may be influenced, or even decided, by the properties of the mould and core materials used. It may, for example, have to be placed in a particular position to avoid damage to the mould or cores during pouring, especially if only comparatively large ladles are available. This position, however, may not give the best distribution of temperature to promote efficient feeding or minimise the danger of cracks.

The provision of internal or external chills to obtain differential cooling in the mould, and of brackets or fillets to prevent hot tears, may interfere with both the running of the casting and the feeding of the other portions.

These and similar factors affecting foundry procedure constitute the reasons why, as mentioned earlier in the present report, foundry practice in moulding, gating and feeding is based on practical experience and works tradition. When castings of new design are called for, the cutting-up and examination of successive initial samples before satisfactory results are obtained are expensive and, what is often more important, waste a good deal of time.

Whilst it is evident that the investigation of running and feeding methods will not of itself solve the problems encountered in every foundry, there is no doubt that the establishment in this field of definite principles which could be applied to steel castings generally would be of considerable assistance and benefit to all technical steel-foundry staff, since it would help to remove some of the uncertainties which constantly confront them.

The investigations carried out on the castings 12 in., 18 in. and 24 in. long were designed to find out how far the head which would feed a 6-in. cube casting would feed in a horizontal direction longer castings of similar cross-section, and it was shown that satisfactory horizontal feeding did take place with the same type of head up to a length of 18 in. When the length of the casting was increased to 24 in. long it was necessary to use a larger head. The effect of horizontal feeding is that the longer the casting in relation to its cross-section, the less is the percentage of head required when the head is placed at one end, the runner end. The Sub-Committee have not had time to determine the effect of varying the position of the head on the longer castings. It has been confirmed that insulation round the heads and the use of feeding compounds makes a marked difference to the results.

The "Whirl-Gate" Head and the "Atmospheric" Head

The Sub-Committee express indebtedness to Mr. Basil Gray, of the English Steel Corporation, Ltd., for the pioneer work he has done in developing the so-called "whirl-gate" head method of feeding castings.

The whirl-gate head, as it is now understood, is something more than a spinning ingate. It should consist of a head so placed and with such a short connection to the casting that the relative feed through this neck is increased by the heating effect on the sand caused by the proximity of the head to the casting. To this effect is added that of spinning the steel at the bottom of the head by a whirling or tangential ingate. As much of the value of this form of head comes from its careful placing as from the spinning ingate.

The Sub-Committee agree that the whirl-gate head method of feeding, correctly applied, with its consequent saving in dressing cost, is one of the outstanding advances in steel-foundry technique for many years. The bad results which many people get with the whirl-gate head are due to lack of knowledge as to (a) how close the head should be to the casting, and (b) the height of the connection portion between the head and the casting. Several examples are illustrated in the Report.

Feeding Compounds

Carefully controlled trials have been carried out by members of the Sub-Committee to check the efficiency and synthetic feeding compounds, with the object of determining the best type of compound, and to discuss the reasons for the behaviour of different types.

Chemical analyses of trade compounds showed wide variations in the ideas of the manufacturers, and steel foundrymen had likewise exercised their ingenuity to find the best compound for their own use. The various types used may be summarised as follows:

- (1) Heat-evolving types containing aluminium powder and iron oxide with an inert filler powder (some of the low-melting point mixtures giving fluid slags).
- (2) Similar types to (1) with increasing amounts of carbonaceous matter.
- (3) Finely ground or "falling" electric furnace slag, with pieces of charcoal robbed into the slag after casting.
- (4) Papier-maché shapes (may be satisfactory for ingots, but quite useless for castings, where the heads are usually smaller and of various sizes and shapes).
- (5) Chopped straw.
- (6) Impure blacklead, with about 40-50% of ash.
- (7) Finely ground coke dust or coal dust with adulterants.

The Sub-Committee's test results showed that the best type of feeding compound was No. 6, and the reason for its success was that as the carbon burned away slowly it left on the surface of the fluid steel a light flocculent type of ash, which formed an ideal insulation of the surface of the steel in the head. Compounds containing thermite (No. 1 type) produced a narrower and deeper pipe which tended to extend into the casting, but it was noticed that as the percentage of carbonaceous matter was increased the efficiency of the compound improved. Attempts to simulate the No. 6 type by making No. 3 (charcoal and slag) or No. 7 (coke dust and fine dust)

did not succeed, because the ash layer left on the surface was not as insulating as that left when an impure black-lead burns slowly.

Chopped straw is used successfully on large heads and depends for its efficiency on the same effect, that is, it chars slowly and leaves a light insulating layer on the steel in the head.

Hot Tears

(1) Cracks which occur in steel castings during manufacture may be divided into two classes, namely:

Class 1.—Cracks controlled by Composition, Fluidity and Design.

(a) Shrinkage cracks, hot tears or pulls, visible on the surface when the casting is removed from the mould and shot-blasted.

(b) Internal shrinkage fissures, which may or may not become visible after the surface has been scaled in heat treatment.

(c) Internal laps, which spread outwards and appear as horizontal cracks on the vertical faces of castings after heat treatment, particularly treatments involving quenching. They are seldom seen in carbon-steel castings.

Class 2.—Cracks controlled by Composition, Design and After-Treatment — commonly called "Clinks."

(a) Clinks caused by the release of casting stress or heat-treatment stress.

(b) Clinks developed by local applications of heat, as in uneven or too-rapid heating for annealing, &c., burning-off operations and welding.

(c) Clinks caused by the release of stress set up by heavy machining.

This part of the report deals with the class 1(a) type of crack, better known by the foundry terms "hot tears" or "pulls," and distinguishable from the cracks of class 2 by the nature of the path of the crack across the casting. A hot tear follows a tortuous path across the face of the casting and the crack has jagged edges, whereas a "clink" follows a straight path.

All steel foundrymen know that hot tears can be avoided by design modifications, the choice of low-sulphur-content steel, adequate fluidity of the steel, the use of green sand in cores or in portions of moulds which would offer resistance to the free contraction of flanged portions of castings, or by digging out intervening sand (easing) to allow the casting to contract without restriction immediately after solidification has taken place. The problem that was set to the Sub-Committee, however, was to formulate methods of a practical nature which would furnish a numerical index of the tendency of a given steel to hot-tear in moulds. Attention is drawn to the fact that the degree of hot-tearing in a particular design can be minimised or often eliminated by using steel with a lower sulphur content.

War-Time Activities

The long-term programme of foundry research envisaged by the Sub-Committee had to be curtailed during the busiest years of the war period, as increasing calls were made on the Members for their attendance on other committees set up to deal with problems of design modifications and production schemes—work which cannot be reported to the Institute but which served the useful purpose of bringing together, for the common good, steel-foundry executives from all parts

of the country. One interesting example of the spirit of co-operation which has grown up is the scheme whereby a foundry making satisfactory samples of a new design would prepare and circulate drawings showing full moulding details for the assistance of other steel foundries called upon to make the same casting.

For a time the meetings of the Sub-Committee had to be discontinued, except when foundry questions of a general nature were submitted by Government Departments for concerted action. Many of the smaller steel foundries were being called upon to produce castings of which they had had no experience, and one problem which was quickly solved from the experience of members of the Sub-Committee without the necessity of carrying out foundry experiments was the replacement of cast-iron solid practice shells, 8 in. and 16 in. in dia., by cast steel to a rigid mechanical-test specification. The foundry had been attempting to produce these solid shells in sand moulds, and had encountered circumferential and longitudinal cracks, revealed when the surface was removed in machining. Other foundries were able to report that success had been achieved by casting into ingot moulds of special shape, and it was recommended that the new foundries should be put into contact with those steelmakers who had made these shells successfully. It was further recommended that any steelmaker undertaking the manufacture of these shells should have facilities for machining the casting, or be able to keep in close touch with the machining results during the early stages of manufacture, in order that steelmaking variables, casting temperatures and pouring speeds could be correlated with the incidence of defects and the necessary steps taken to build up a satisfactory technique from this experience.

Another urgent problem investigated by the Sub-Committee was the possibility of providing cast-steel target plates, 4 ft. 0 in. square by 10 mm. thick, which must be uniformly sound throughout to test small-arms ammunition. Sample plates 2 ft. 0 in. square were cast in carbon steel in two thicknesses, 10 mm. and 20 mm., and X-ray examinations were made to determine the influence of different methods of gating and heading. Conclusion was reached that, whilst it seemed difficult to obtain sound 10-mm. plate of this area, the problem was simpler in the case of the 20-mm. plate. The X-ray examinations showed that the fluidity of the steel was of great importance in obtaining soundness. Adequate soundness in a 10-mm. thick plate was obtained only by running 10° uphill, with four good heads on the face of the plate. When vertical or horizontal casting was attempted with heads at the edges of the plate, it was apparent that the 10-mm. section was too thin to permit satisfactory feeding to overcome centre-line weakness.

The use of substitute moulding materials and the increasing interest in methods of desulphurisation and dephosphorisation following the deterioration in the qualities of raw materials available for steelmaking have been discussed by the Members in collaboration with the relevant Sub-Committees of the Institute.

Fundamental Casting Problems

With a return to more normal conditions the Members of the Sub-Committee will be able to devote their attention to the co-operative study under practical foundry conditions of the programme set out in Part 1 of this Report. Whilst it is true that every new design must be dealt with separately and different foundries

often mould and run similar castings in different ways to suit the available equipment, it is hoped that the work will tend to clarify the principles involved in producing sound steel castings in the most economical fashion.

Investigations dealing with the effects of variation in the rates of pouring castings in different foundries and with methods of feeding 100-mm. thick plates are already in hand. In addition, the Sub-Committee are preparing a pamphlet on the "Design of Steel Castings,"

Town Gas for Welding

THE difficulty of replacement of plant is likely to continue for some time to come. Labour and materials will still be difficult to obtain and the time taken to replace broken or worn-out plant will cause repairs to existing plant to take precedence over the purchase of replacements or new plant. The impossibility of giving the same care and maintenance during the stress of war production, as is customary under normal conditions, will make a very great deal of reconditioning necessary after the war. Moreover, machinery that was built or altered to produce the engines of war, will require modification before it can be used for the arts of peace. These repairs and modifications must be done quickly if the change-over to peace production is not to be delayed.

That these operations provide an enormous field for the application of welding, was the theme of an address recently given by Mr. C. W. Brett, in the course of which he paid eloquent tribute to the value of coal gas for welding. During the war most branches of engineering have made advances, and perhaps in none has the advance been more notable than in welding. Not only has the range of welding been extended so that welding has now become standard practice for certain classes of work for which it was once considered impossible, but; at the same time, there has been a steady trend towards a reduction in welding costs, in which town gas has played a not unimportant part. The quality of welded work has also been very materially improved. Welding, however, must still be considered as a job for the specialist, and much of this repair and reconditioning work is now undertaken by specialist firms who are prepared to guarantee their work.

The use of oxygen and of the electric arc enabled very high temperatures to be available for welding. These high temperatures, in Mr. Brett's opinion, have, in some cases, been a handicap rather than an advantage because they were higher than was necessary to obtain a satisfactory weld. The use of town gas has enabled lower temperatures to be applied, and it has played no small part in the more precise regulation of heat so that a pre-determined maximum temperature is thereby obtained immediately and held steadily for as long a period as may be necessary.

One advantage of this more accurate control of temperature has been that it has greatly reduced the need for pre-heating castings prior to welding. There are, however, frequent occasions upon which heat-treatment is the key to success, not only for welding but also for annealing, or "stress-relieving" as the final step before machining, or otherwise finishing the job. The furnaces used for this purpose are almost invariably

which, it is hoped, will have a wide circulation in the engineering industry and serve the purpose of bringing together the foundry executives and the designers while designs of steel castings are still on the drawing board.

The future progress of the steel castings industry depends on the co-operation of the foundry executives, who have already given so much of their time and experience, and on the generosity of individual manufacturers, who have carried out the practical experiments recorded in this Report at their own expense.

fired by town gas. Sometimes this work can be done in standard furnaces maintained for the purpose, but, on occasion, the shape or size of the welded component may be such that a special furnace must be built round the welded vessel, or machine or component and the gas laid on. A large repair job may thus require thousands of cubic feet of town gas.

Welding methods are often divided loosely into electric and oxy-acetylene welding, but to-day it is more accurate to refer to the latter category as "gas welding." Whilst the oxy-hydrogen flame was the first to be applied with practical success the oxy-coal-gas flame was introduced quite soon afterwards, and has continued to prove of great value. One important branch of work in which the oxy-coal-gas flame has pronounced advantages is metal cutting; this is especially true of profiling machines where accuracy is combined with quantity production in a remarkable manner. Even gear wheels and sprocket wheels can be formed by this method with such accuracy that no subsequent work is needed upon the teeth apart possibly from the removal of a little scale or burr.

The range of coal gas welding is not always appreciated. It can be used upon massive castings having a broken section of 10 inches or more in thickness. In contrast to this, tiny precision components can be restored to a condition equal to new, whilst other parts that are merely worn can be built up afresh, and then machined to any tolerance that may be specified. The component will show no trace of the repairs that have been effected and can be slipped into position without the need for fitting. Thus the bottle-neck of replacement of damaged or worn parts has been overcome by gas welding.

The Institute of Physics

The X-ray Analysis Group of the Institute of Physics announced that its 1945 Conference (the fourth in the series) will be held on the 12th and 13th April next, at The Royal Institution, London, under the chairmanship of Sir Lawrence Bragg. The programme includes a lecture by Prof. J. D. Bernal on "The Future of X-ray Analysis," and a series of papers on new and improved methods. Discussions are to be included on the equipment of a laboratory for X-ray analysis, the interpretation of X-ray diffraction by optical principles, and the proposal to convert X-ray wavelengths to absolute values.

Further particulars may be obtained from Dr. H. Lipson, F.Inst.P. (the honorary secretary of the Group) Crystallographic Laboratory, Free School Lane, Cambridge.

Charging Electrical Steel and Other Furnaces

THE charging of electrical steel furnaces may be performed either by skips containing the charge of metal carried by an overhead crane or by charging the metal through doors in the sides of the furnaces. The former method is illustrated in Fig. 1, in which the furnace roof is raised and swung to one side, so that the crane can approach with the loaded skip. When in position the skip bottom is released and the charge deposited in the furnace. In this way the metal to be melted is placed in the furnace in one movement.

Electric steel furnaces with side doors have, if of large capacity, hitherto been charged by means of overhead machines or chargers running on rails placed on the platform. Smaller furnaces have, on the other hand, for the most part been charged by hand. This is a laborious and time-taking process, involving loss of heat, particularly if the scrap metal to be handled is light and of irregular formation. In order to accomplish furnace charging quickly, mobile type box chargers have been developed and successfully employed in many works. These run on the platform, picking up the charging boxes from stands placed at convenient points. For this purpose the charging machine is provided with a tee-headed bar, which is carried in a rocking frame, provided with trunnions and rocking hoist gear, as well as a locking bar to secure the charging boxes. Fig. 2 illustrates a machine of this type built by the Wellman-Smith-Owen Engineering Corp. Ltd., London.

It will be noted that the machine is carried on three points, the front wheels being mounted on a through-going axle. The rear end is carried on a castor which constitutes the driving and steering element. This castor is provided with dual solid rubber tyred wheels and is driven by an electric motor. It is capable of turning about a vertical king post through an angle of 90° on each side of the central position. This permits of a minimum turning radius equal to the wheel base of the machine, and it is, therefore, capable of manoeuvring in a comparatively small space. The rocking hoist motion may be operated either electrically or hydraulically, but the bar turning gear is arranged for hydraulic operation only. A constant running motor and oil pump supplies the hydraulic power, thus the advantage is

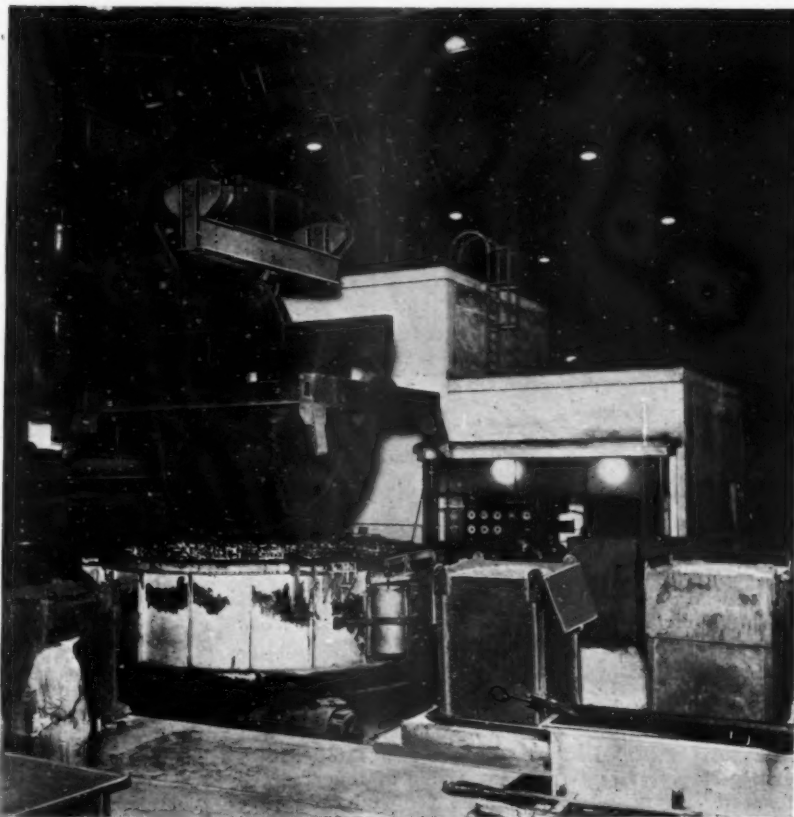


Fig. 1.—The complete charge for an electric steel furnace of large capacity suspended on a Wellman overhead travelling crane, ready to be charged into the furnace in one movement.

gained of a reduction in the stored energy of the moving parts, as compared with separate electric drives, thereby effecting a saving in the starting and stopping movements. Furthermore, the parts incorporated in the drive are small in bulk, which is a feature of importance, making for compactness in design and ease in maintenance.

The mobile charging machine may pick up its current supply either through a flexible cable and drum or by means of a trolley pole with collectors running on an overhead track whichever may be found the more convenient. Machines may also be built for operation by means of oil engines, making them independent of any electric current supply. In actual service it is found that the mobile charging machine materially reduces the time required for charging a furnace as compared with hand charging. This in turn means that the output of the furnace charged is increased and a saving in manpower is effected. The machine may be equally well employed for the charging of the

smaller sizes of open-hearth steel furnaces, also cupolas.

Mobile, billet, bloom, ingot and slab charging machines and also forge manipulators, generally based on similar lines to the box charger, are also finding increased employment, and may be used for handling steel or non-ferrous metals. They are mounted as before on three points, a dead front axle and a driving and steering castor. The latter has, however, an axle pivotted at its centre to the lower end of the kingpost and the wheels are spaced apart, permitting employment of a dual motor drive. With the two motors wired in series no differential gear is therefore required and the gears are simple in design and easy of access. This type of castor has the further advantage that owing to the fact that it is symmetrical in form it requires the least possible space and enables the side frames to be carried outside and as low as ground clearance permits. With a low chassis practically all the working parts of the charging machine are situated above the framework level and are accordingly readily approachable. The driver has his post at one side of the machine and obtains an unobstructed view.

The charging bar in a forge handling machine or manipulator has, of course, several features not found in a box charger. In the first place it is fitted with a grip gear consisting of a heavy pair of tongs at the forward end, with grips to suit the material to be handled and which are operated by a powerful hydraulic cylinder at the rear end. In order to maintain an active grip as compared with the action of merely obtaining the grip by closing the valve, an air-loaded plunger is placed in the pipe line. As soon as contact is made by the grips the oil pressure rises, thus compressing the air and forcing oil into the plunger casing. On closing the valve the plunger is urged forward, maintaining the active pressure required on the cylinder. In the case of forge manipulators provision is also made for shock absorption by means of air pressure during the act of pressing or hammering the forging.

The mobile machines are, as already mentioned, driven from a point at one side, the controls being grouped to form a unit placed in a convenient position to the right hand of the driver. Steering of the machine, being hydraulically operated under control of a follow-up valve (Patent No. 367,241), is so arranged that the angularity of the castor and the steering wheel agree in direction and amount, avoiding any tendency to wander.

Generally speaking, mobile charging machines and manipulators are made in any capacities, provided that sufficient space for their free movement is available.



Fig. 2.—A mobile type box charging machine, developed by Wellman and successfully employed in many works.

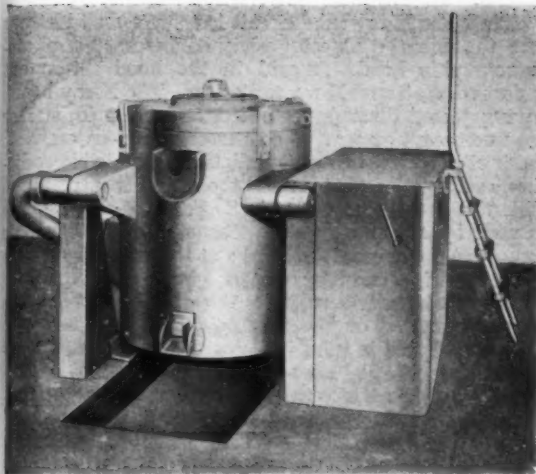
They are equally applicable to the handling of the lightest forgings, such as axles, shafts, coupling rods and various other work pieces.

A Power Tilting Crucible Furnace

A RECENTLY developed melting unit, capable of supplying medium and large quantities of metal, incorporates a number of useful features, including hydraulic tilting and a removable body, to ensure labour-saving and trouble-free operation, with minimum maintenance and running costs. It is designed as a general purpose melting unit, suitable for a variety of uses, including sand castings, billet and strip castings, and many other processes involving the use of molten metal. It is a product of the Morgan Crucible Co. Ltd., Battersea Works, London, S.W.11, and the main features are as follows:

Compact Design.—The furnace is of sturdy construction, designed to withstand heavy foundry usage with minimum maintenance charges. It is compact and the overall size and floor area covered are considerably less than for a hand tilted unit. The operating points—burner control, tilting control, and platform—are grouped within a minimum height of each other and arranged at a convenient level, so that the effort required to run the furnace is reduced to a minimum.

Power Tilting.—Tilting is effected through an oil hydraulic system, consisting of a telescopic ram at the back of the furnace, served by a motor-driven pump and small reservoir housed under the furnace platform. The operation of tilting is semi-automatic, simple and fool-proof, controlled by the operation of a single valve lever. The lever projects through the platform panel and is spring loaded in the "shut" position, so that when released by the operator during tilting the furnace locks in position. The lever also incorporates push button



New type of crucible tilting furnace incorporating hydraulic tilting as a standard feature.

control of the pump motor, which is, therefore, run only when necessary, i.e., when the furnace is tilting up. The operator thus controls the tilting and motoring with one hand by a single lever. Special arrangements can be made to run two or three furnaces from a single hydraulic system.

Lip Pour.—The tilting axis passes through the line of the pouring spout, so that the furnace gives a fixed pouring stream throughout the tilt. The charge can, therefore, be poured direct from the furnace without having to move the work, whether it be billet, strip or special mould, or foundry ladle.

Removable Body.—The furnace body is made removable, so that it can be easily and quickly taken out

and changed for a spare one. The tilting shafts lie in open bearings and the body is removed simply by swinging the burner clear of the injector box, disconnecting the ram, and lifting out. This feature is designed to enable the furnace to be kept in continuous production, and to avoid lengthy periods of idleness, during which the furnace is shut down for lining and other repairs or replacing the crucible.

Tilting Burner.—The burner is arranged to tilt with the furnace which can, if desired, be fired whilst in a tilted position. This feature is of particular value in cases where the pouring operation is of a protracted nature and it is essential to keep the charge up to a definite temperature throughout the pour. Oil- or gas-firing can be arranged. The oil furnace is suitable for all fuel oils and creosote pitch; the gas fired version is supplied for either town or producer gas. Producer gas firing is recommended as suitable for aluminium alloys only.

Range and Output.—Four sizes, ranging from 600 lb. (brass) to $\frac{1}{2}$ ton (al.) capacity, as shown below. The first three are suitable for the general range of non-ferrous and aluminium alloys, whilst the largest size is limited to aluminium alloys only. The 600 lb. size will also handle special cast irons. The furnace has a high rate of output, as can be seen from the following table, giving the melting rate and fuel efficiency. The figures cover the melting of ingots or clean scrap to normal pouring temperatures under continuous working conditions over a full shift, and are for oil firing.

Furnace	Size	Aluminium			Brass			Copper & Nickel Brass		
		Charge (lbs.)	Time	Fuel (%)	Charge (lbs.)	Time	Fuel (%)	Charge (lbs.)	Time	Fuel (%)
600 lbs.	(br.)	220	30,	13	650	55,	9	650	1-15,	13
$\frac{1}{2}$ -ton	"	375	35,	12	1120	1-10,	8	1120	1-35,	12
$\frac{1}{2}$ -ton	"	560	40,	11	1680	1-13,	8	1680	1-40,	11
$\frac{1}{2}$ -ton	(al.)	1120	1-15,	10	—	—	—	—	—	—

Electronic Timing for X-Ray Exposures

A photo-electric X-ray timing device now enables radiologists and technicians to obtain uniformly dense photofluorographic exposures with an overall increase in operating efficiency, claimed to be about 100%. The electronic timer, developed by Westinghouse Electric and Manufacturing Company, according to H. D. Moreland, times each exposure properly, quickly, and automatically and, in view of its industrial possibilities, brief reference is made to this development.*

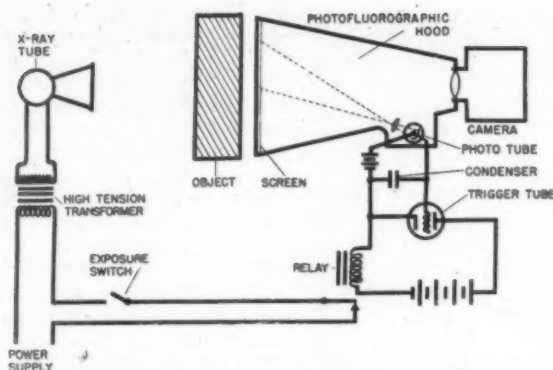
AN electronic method controlling X-ray exposures has been developed, enabling radiologists and technicians to obtain uniformly dense photofluorographic exposures automatically, rapidly, and with an overall increase in operating efficiency of about 100%. The photoelectric timer operates on the principle of the exposure timer which amateur photographers use. X-ray radiation, passing through an object, strikes a fluorescent screen and is converted into visible radiation. A section of the luminous screen is scanned by a photoelectric tube which, in effect, measures the light leaving the screen. When enough light has left the screen for the desired film exposure, the photoelectric timer actuates a relay, opening the X-ray circuit and terminating the exposure.

Although first used in medical radiography for mass chest surveys on miniature roll films, the development will undoubtedly be generally useful and will include

industrial X-ray analysis. Objects such as castings, conducted on conveyers, can be inexpensively, quickly, and uniformly photographed on miniature roll film, using the photoelectric control. Large, irregular objects need only be positioned before the screen. Since the photoelectric control responds to the actual light on the screen, deviations in the internal structure of the object X-rayed will not deceive the timer, and the result will be films of desired density, analytically satisfactory, attained with minimum cost.

Efficient photofluorography requires the examination of many objects in reasonable intervals of time, and the procedure must be simple enough to require a minimum of operating personnel. There must be extreme uniformity between films for maximum analytic value, and the number of improper exposures requiring repetition must be small. The electronic timer fulfils these conditions so adequately that the operator need only position the object before the fluorescent screen and close the exposure switch by a touch of the hand. The

* H. D. Moreland, Manager, X-Ray Engineering, Westinghouse Electric and Manufacturing Company, Baltimore, Maryland, U.S.A.



The schematic diagram reveals the ingenious simplicity of the photoelectric timer. Closing of the exposure switch energizes the X-ray tube and radiation passes through the object. Undesired, scattered radiations are filtered by a grid and the direct X-ray radiation strikes the fluorescent screen where it is converted into visible light radiation. The light is picked up by the photographic camera lens and by the phototube lens which scans a representative section of the fluorescent screen, focusing the light on the photoelectric tube. The resulting current charges a condenser and when the proper potential is attained the trigger tube fires, actuating a relay which opens the circuit and terminates the exposure. The circuit is so designed that the timer maintains a constant exposure factor. Thus, if very dense objects are being photographed, the timer maintains the exposure a relatively longer time. Since the phototube sees precisely what the photographic camera sees, the timer functions independent of internal irregularities in the object, providing uniform, quick exposures.

timer then not only terminates the exposure at the proper moment, but an auxiliary circuit prevents overloading the X-ray tube.

Principle of the Electronic Timer

The timer takes advantage of the nature of the photoelectric tube, whose output is proportional to the light striking the cathode. The principle of this timer can be easily seen in a simple circuit consisting of a photoelectric tube, a relay circuit, a sheet of frosted glass, a partially transparent object, and a light source. If the light source is turned on, a certain amount of radiation passes through the rather dense object and reaches the frosted glass. The light from the screen impinges on the tube and a proportionate current flows in the phototube circuit. At a predetermined exposure factor (the product of the light intensity and the time), the photoelectric tube actuates the relay and the light turns off. If an object considerably denser is introduced between the light and screen less light reaches the phototube and the current output is correspondingly less. This means that the photoelectric tube will permit the light source to radiate for a longer period of time, so that a constant exposure factor is maintained. Deviations in the density of the intervening object vary the output of the tube, and this varies the period during which the light source is permitted to radiate. The tube will not turn off the light until a given quantity of light has passed through the screen, and film exposures in radiography are controlled by the photoelectric timer in just this fashion.

The electronic timer consists primarily of a multiplier photoelectric tube and a condenser-thyratron-relay system. When the exposure switch of the X-ray unit

is closed, the X-ray tube circuit is energized and X-rays pass through the object positioned before the photofluorographic hood. A grid in the hood filters out undesired, scattered X-ray radiations. The X-ray beam, having passed through the object and the grid, strikes the fluorescent screen. The fluorescent screen converts the invisible electromagnetic radiation into visible radiation, and light emanates from the screen in accordance with the density of the object. Some of the light is focused by a lens on to the film of the photographic camera at the apex of the hood; at the same time, some of the light is focused by another lens on to the cathode of the photoelectric tube in the so-called phototube camera mounted on the lower side of the hood. The light entering this tube initiates a small current proportional to the light intensity of the scanned section of the fluorescent screen. This current charges a condenser and produces a potential which increases as the collected charge increases. The condenser voltage is impressed across the grid and cathode of a trigger tube and fires the tube when the necessary ionization potential is created. The circuit elements are chosen so that the ionization potential is attained only when sufficient radiation emanates from the fluorescent screen for proper uniform film exposure. When the trigger tube ionizes and fires, a magnetic relay is energized, which opens the X-ray circuit, terminating the operation of the X-ray tube and the exposure of the film.

Five variables, in general, are involved in X-ray photofluorography: (1) thickness of the object; (2) exposure time; (3) X-ray tube voltage; (4) X-ray tube current; and (5) distance from X-ray tube to fluorescent screen. Prior to the development of the phototimer, the tube current and the distance were the only fixed factors—for example, 200 milliamperes and 40 inches. The radiologist or technician measured the thickness of the subject and in accordance with that measurement altered the applied X-ray tube voltage in steps of one kilovolt over a range of 60 to 100 kilovolts. The necessary exposure time was then estimated and set on a separate motor-driven timer. In all, the procedure involved five steps—measurement of the subject, positioning before the fluorescent screen, adjustment of voltage, setting of the exposure timer, and making the X-ray exposure. Moreover, variations in line voltage necessitated constant checkings and adjustments if properly exposed films were to be obtained.

With the electronic control, the current is set at some particular value, but variations of current (or voltage) are of no consequence, and the exposure time is allowed to vary over a range from $1/20$ to $1/5$ of a second. Only a very rough kilovoltage adjustment is made, based on an estimate of subject size, and the thickness of the subject need not be measured. Using a timer, therefore, the procedure involves merely the positioning of the subject, a rough kilovoltage adjustment in accordance with a quick visual classification, and the touching of an exposure switch. The increased operating efficiency is evident in this comparison. Moreover, since the phototube is affected only by the light intensity from the scanned section of the screen, uniformly good exposures are insured, regardless of the thickness of the object or of irregularities within the object. A skilled technician cannot compensate for invisible, unknown internal irregularities, but the photoelectric timer can, since it is only affected by the light intensity on the fluorescent screen.

Determination of Small Quantities of Nickel in Duralumin

A study has been made of the factors affecting precipitation of the nickel complex in duralumin and, as a result of experimental work carried out, an improvement on existing methods of determining small quantities of nickel is recommended.

THE gravimetric determination of small quantities of nickel in duralumin by means of dimethylglyoxime under conditions that are suitable for larger amounts tends, in general, to yield low results. The Russian chemists, Trikov and Lapshina, of the laboratory of the Moscow Works for the Fabrication of Non-Ferrous Metals, have recently made a study of the factors affecting precipitation of the nickel complex and have recommended an improvement on the existing methods.

In their paper¹ they give results obtained by two recognised procedures carried out on nickel-free sample of aluminium and duralumin, to which they added known quantities of nickel, representing 0.005% to 0.10%. They were unable to obtain a precipitate, even after one day's standing, with contents of 0.005% and 0.01%; they failed to obtain more than a trace or 0.005%, when 0.02% had been added, and results for the higher amounts were uncertain.

The factors influencing precipitation, which were investigated by the authors, are (1) presence of large quantities of nitrates, (2) degree of dilution, (3) quantity and nature of precipitant, and (4) presence of copper salts.

Influence of Nitrates. To the solution of a nickel salt were added 25 ml. of nitric acid (1:1), 25 ml. of hot water and 2 ml. of a 3% solution of dimethylglyoxime in caustic alkali. The solution, after the addition of ammonia to a definite smell, was left for an hour in a warm place for the precipitate to coagulate. For comparison exactly the same operations were carried out on another solution, the only difference being that hydrochloric acid replaced the nitric acid used previously. After one hour's standing, the precipitates were filtered off through weighed filtering crucibles (Schott No. 2). The experiments showed that with a nickel content of 0.0005 g. no precipitate formed in the nitrate medium but that with amounts of nickel, 0.0025 g. and 0.0050 g., the nitrate and the chloride media were equally good.

Influence of dilution. To a hydrochloric acid solution of a nickel salt were added varying amounts of water, 2 ml. of alkaline dimethylglyoxime solution and the determination carried out as described above. The quantity of nickel taken in each case was 0.0005 g. With a total volume of solution of 100 ml., results of 0.00053 g. and 0.0005 g. were obtained, with 150 ml. volume, 0.00047 g. and 0.00041 g., and with 200 ml., 0.00037 g. and 0.00035 g. The lower results at greater dilution are explained by the solubility of the nickel complex.

Influence of precipitant. Hydrochloric acid solutions containing nickel equivalent to 0.0005 g. were diluted to 80 ml. with hot water, varying amounts of 1% alcoholic or 3% alkaline solutions of dimethylglyoxime were added and the same procedure followed as before. The results are shown in Table I.

TABLE I.

Precipitant	Vol. in ml.	Ni. found (g)
1% alc.	4	0.00044
"	10	0.00038
"	50	NH.
3% alkaline	2	0.0005
"	5	0.0005
"	15	0.0005

The fact that incomplete precipitation occurs when the quantity of nickel present is small and an alcoholic solution of dimethylglyoxime is used may possibly be explained by the solvent effect of the alcohol on the precipitate. When the reagent is used in the form of a solution in caustic alkali, even a large excess has no influence on the precipitation.

Influence of copper salts. The investigation concerned the effect of copper in the proportion met with in duralumin (2.5% to 5%) on the determination of nickel up to 0.05%. In the experiments copper was added in the form of copper chloride, obtained by dissolving electrolytic copper in a mixture of hydrochloric acid and hydrogen peroxide.

The first experiments were carried out without the addition of tartaric acid. To the solution of the nickel salt were added 20 ml. of hydrochloric acid (1:1) and copper chloride solution in variable amount. The solution was then warmed to 60° C. and 5 ml. of alkaline dimethylglyoxime added, followed by ammonia in amount sufficient to form the deep blue copper-ammonia complex and to give an excess of 1 to 2 ml. After leaving for 1 hour, or in other cases overnight, the precipitate was filtered off and washed with hot water. The precipitation was repeated by dissolving the compound from the filter in hot dilute hydrochloric acid, adding to the filtrate 2 ml. of the reagent and neutralising with ammonia (the reprecipitation is necessary for obtaining a nickel precipitate free from absorbed copper salts).

After standing in a warm place the precipitate was filtered through a crucible, dried and weighed. The results are shown in Table II. In all these experiments the weight of nickel taken was 0.0005 g.

TABLE II.

Time of standing (hours)	Copper added (g.)	Nickel found (g.)
1	0.05	0.00036
1	0.10	0.00034
1	0.20	0.00030
24	0.05	0.00038
24	0.10	0.00040
24	0.20	0.00036
24	0.50	0.00034
24	0.50	0.00020
24	0.50	0.00016
24	0.50	Traces

From Table III it can be seen that the time of standing does not play a great part. There is no significant difference when the copper content is increased from

I. M. D. Trikov and V. A. Lapshina, *Zavod. Lab.*, 1941, 10, pp. 253-256.

0.05 g. to 0.2 g., but a larger content (0.5 g.) has a considerable effect on the precipitation of nickel.

Further experiments were carried out in which the quantity of copper (0.2 g.) and the time of standing (24 hours) were kept constant but the quantity of nickel was varied. Results are shown in Table III.

TABLE III.

Nickel taken (g.)	Nickel found (g.)
0.00025	0.00014
0.00050	0.00038
0.00250	0.00258
0.02500	0.02495

Influence of copper in the presence of tartaric acid. A 25% solution of tartaric acid was introduced into the hydrochloric acid solution of the nickel and copper salts. The results are set out in Table IV.

TABLE IV.

Copper taken (g.)	Nickel taken (g.)	Nickel found (g.)	Remarks
0.05	0.0005	0.0005; 0.00049	Tartaric acid, 10 ml.
0.10	0.0005	0.0005; 0.00049; 0.00047	
0.20	0.0005	0.0005; 0.00049; 0.00045	
0.25	0.0005	0.00049; 0.00045	
0.50	0.0005	0.00045; 0.00040	Tartaric acid, 40 ml.
0.50	0.0005	0.0005; 0.0005	
0.50	0.0250	0.0254; 0.0250	

From the data of Table V it is obvious that, in the presence of tartaric acid, the retarding action of copper ions hardly shows at all. It is only with a large quantity of copper that precipitation becomes incomplete, but this effect is counteracted by the addition of a large excess of dimethylglyoxime or a large quantity of tartaric acid.

Further experiments were carried out in which citric acid was used in place of tartaric acid, citric acid being used frequently in laboratories for this determination. The results showed that small quantities of nickel were incompletely precipitated when copper was present. Thus tartaric acid is a stronger complex-forming compound than citric acid.

Recommended method of analysis. On the basis of the above results the following method was worked out:—

5 grams of duralumin are placed in a 500 ml. conical flask and treated in the cold with 50 ml. of 15% caustic potash solution followed by a further 50 to 70 ml. when the vigorous reaction is over. After bubbles of hydrogen cease to be evolved 100 ml. of hot water are added, the solution heated to boiling and kept in this state for 1 to 2 mins.

The insoluble matter, consisting of copper, iron, manganese, magnesium and nickel, is filtered off, washed 6 times with hot water, treated on the filter with a mixture of 5 ml. of hydrogen peroxide (1:5) and 20 ml. of hot hydrochloric acid (1:1), the filter washed 4 times with hot water and the filtrate and washings collected in a 200 ml. beaker. The solution is boiled to remove chlorine and evaporated down to 20 ml. The beaker is then removed from the hot-plate, cooled somewhat, the solution treated with 15 ml. of 25% tartaric acid and neutralised with ammonia

to the formation of the deep-blue copper-ammonia complex. Then, after the addition of 1 to 2 ml. excess of ammonia, the solution is carefully stirred with a glass rod and examined for the appearance of cloudiness or precipitate. Should there be a precipitate it is left to coagulate, filtered off and washed three times with hot water, the filtrate being collected in a 150 ml. beaker. The solution is acidified with hydrochloric acid (1:1) and evaporated to 50–60 ml. To the solution, cooled to 60–70° C., are added 5–6 ml. of 3% alkaline dimethylglyoxime (30 g. of dimethylglyoxime dissolved in 1 litre of 3% caustic potash) and then ammonia to form a deep-blue colour and 2 ml. in excess.

If no precipitate of the nickel compound appears immediately (nickel less than 0.01%) the sides of the beaker should be carefully rubbed with a glass rod whilst the beaker is cooled in a stream of cold water.

The solution with the precipitate is left for 2 hours on a moderate heat to coagulate the precipitate. It is then filtered through a paper (white band), washed three times with hot water and dissolved in 10 ml. of hot hydrochloric acid (1:1). The filter is washed four times with hot water and the filtrate and washings treated with 2 ml. of 25% tartaric acid, 2 ml. of dimethylglyoxime and then with ammonia till it is neutral to methylorange. A further 1 ml. of ammonia is added and the precipitate left at a moderate heat for 30 mins. to coagulate.

The precipitate is filtered through a previously weighed crucible (Schott No. 2) washed 8 times with hot water, dried in an oven at 110–120° C. for an hour, cooled in a desiccator and weighed. The result is calculated from the formula:—

$$\% \text{ Ni} = \frac{\text{Wt. of ppt.} \times 0.2032 \times 100}{\text{Wt. of sample}}$$

where 0.2032 is the conversion factor of $\text{C}_8\text{H}_{14}\text{N}_4\text{O}_4\text{Ni}$ to Ni.

The method was tested out on the Ural Institute of Metals standard sample No. 69, with the introduction of known amounts of nickel, in hydrochloric acid solution, to the solutions in acid of the caustic potash insoluble matter. Results, referring to a sample weight of 5 g. are shown in Table V.

TABLE V.

Nickel added (%)	Nickel found (%)	Difference (% of sample)
Nil.	Nil detected	—
0.0050	0.0052	+0.0002
0.0050	0.0052	+0.0002
0.0100	0.0104	+0.0004
0.0100	0.0102	+0.0002
0.050	0.052	+0.002
0.050	0.053	+0.003
0.050	0.051	+0.001
0.100	0.103	+0.003
0.50	0.51	+0.01
0.50	0.50	—

It is considered that results obtained by this method should be accurate to 0.0002% up to 0.01% of nickel and accurate to 0.005% at 0.05% nickel.

2. This is a standard analysed sample of duralumin with the composition:—Cu, 4.41%; Mg, 0.64%; Mn, 0.69%; Fe, 0.19%; Si, 0.34%. (Note by translator.)

The Yielding Phenomenon of Metals

Influence of Speed and Loading Conditions

Part III

By Georges Welter

Professor of Applied Mechanics, Ecole Polytechnique, Montreal.

The yielding phenomenon of metals, of importance in applied mechanics as well as in metallurgy, is not yet sufficiently understood. Besides a theoretical consideration, the various factors which have a pronounced influence on the yielding of metals such as the kind of testing machine with its load-indicating device, as well as the rate of plastic deformation of the specimen, have been investigated. In order to obtain additional results about the loading conditions of the specimen, a new direct loading machine with a special recorder was designed, and the stress-strain diagrams of this machine were compared to those of the rigid straining machine. Furthermore, the transmission of the loads from the machine into the test specimen without harmful secondary effects was studied by means of three types of newly developed universal joints which allow loading the specimen axially.

In order to understand the whole stress-strain diagram, an automatic time chronograph was designed.

Furthermore, the characteristics of the two types of machine, the rigid straining machine and the direct loading machine, were compared to each other during the static loading tests, as well as during the dynamic tests with the machine in normal operation. During these tests an artificial yielding effect was obtained by a relative displacement of the loading faces of the machines. Stress-strain diagrams were recorded under different loading conditions; diagrams showing a most characteristic difference between these two types of machines were obtained.

By means of a special device based on sliding friction between three plates screwed together, the dynamic behaviour during yielding of metals in both types of testing machines was analysed and interesting diagrams were recorded. The rigidity of the straining machine could be gradually decreased by inserting elastically stressed elements between the grips and the frame of the machine. In five different steps the characteristics of the rigid straining machine were gradually made nearly equal to those of the direct loading machine.

Comparative tests with usual extensometers measuring in different places the relative movements of the grips and the loading faces of the machine gave valuable indications about the reliability of these instruments.

The upper and lower yield-points of mild steel were studied in function of the speed between about 400 lb. and 20,000 lb. per min. These tests show that the lower yield-point is much more affected by high deformation speed than the upper yield-point.

Time-controlled stress-strain diagrams show in all loading phases important variations of the loading speed in the rigid straining machine and the straining speed in the direct loading machine. The difference between the two types of machines becomes especially effective by comparing the stress-strain diagram of duralumin test specimens tested shortly after quenching and showing a very characteristic yielding effect.

C—CHARACTERISTICS OF THE TESTING MACHINES USED

As already shown, it is necessary to have a clear conception about the principal characteristics of the testing machines themselves before undertaking without error investigations on the behaviour of the test-piece, especially its upper and lower yield-points and its breaking stress. It is obvious that sudden changes in the test-piece during the loading process may react on the balance of the force distribution in the machine. On the other hand, this force equilibrium is of prime influence on the characteristics of the test specimen itself, and as far as possible a separation of these two effects, that of the machine and that of the specimen tested, is necessary—

that is, the characteristics of the testing machine during the loading process in function of changes in the test specimen by constant and sudden static and dynamic deformations have to be investigated first. For this purpose the rigidity of the testing machine used was, as a factor of prime importance, taken under consideration.

(a) Rigid straining machine

The usual testing machines are, as is well known, very sensitive to small variations of the distance between the loading faces. Most of these machines have such a high sensitivity that a displacement of only a few thousandths of an inch between the tables under loads of 8,000 lb. to 10,000 lb., for instance, provokes a sudden drop of

the load on the indicator, and consequently in the machine itself of a few thousand pounds. In Fig. 35 are represented some results obtained on the Baldwin Southwark Universal testing machine, shown in Fig. 7, with the loading ranges of 12,000 lb. and 2,400 lb. For this purpose a special device permitting a very fine regulation of its two loading points in the axis of the applied loads was used. It is necessary that this regulation can take place under applied loads up to 10,000 lb. The device A represented in Fig. 36, working only under compression loads and fixed to the Baldwin machine, permits by means of a hand-wheel B a very fine regulation between the cross-heads of the machine under loads. By a worm-gear placed inside

the body of this device, a so-called "Erichsan" ductility tester, a very fine regulation of the distance between the loading faces of the machine under load could be obtained. One revolution of the hand-wheel B changes the distance between the grips of the machine of about $\frac{1}{1000}$ in., so that it was easy to change the distance of 0.005 in. and 0.01 in. by one-quarter and one-half of a revolution of the wheel; displacements of this value were used in the tests represented in Fig. 35. It

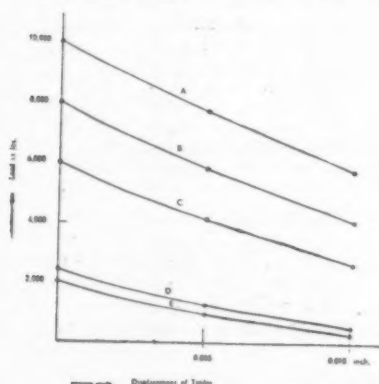


Fig. 35

seems that displacements of a few thousandths of an inch up to about one-hundredth of an inch are in some accordance with the order of magnitude of the displacements of the loading devices of the machine, if, for instance, a steel specimen of standard dimensions shows an initial plastic stretching while the load drops down from the upper to the lower yield-point. Thus, for instance, for a displacement of 0.005 in., the load drops in the middle range of the machine from 10,000 lb. down to 7,720 lb., and for 0.01 in. even as low as 5,740 lb. (curve *a*, Fig. 35). In about the same proportion the load falls down in this range for the initial load of 8,000 lb. and 6,000 lb. (curves *b* and *c*). It is interesting to note that this machine showed a yet higher sensitivity in the low range of maximum 2,400 lb. Here the applied load by a displacement of 0.005 in. fell to 1,260 lb. (curve *d*) and for 0.01 in. to 525 lb. For a maximum load of 2,000 lb. the drop of the load was yet greater, and a displacement of 0.005 in. provoked a loss of more than 50% and 0.01 in. of about 85% of the load (curve *e*), Fig. 35.

About the same sensitivity of the load-indicator in function of the displacement of the cross-head was found for a universal Riehle testing machine,

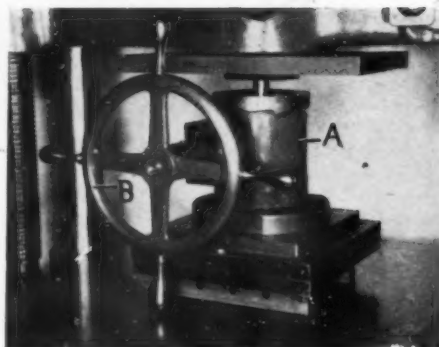


Fig. 36

also a hydraulic machine of 60,000 lb. maximum load, as well as for an Olsen universal machine of the lever type with a maximum of 100,000 lb. The results found with these machines are represented in Figs. 37 and 38.

(b) Direct loading machine

Completely different results are obtained with the direct loading machine regarding the dropping of the load in function of a displacement of the cross-heads. The load indications were again noted for displacements of 0.005 in. and 0.01 in., and this in the ranges of 2,000 lb., 1,500 lb., 1,000 lb., and 500 lb. as initial loads. The displacements between the cross-heads of the machine were made by means of a

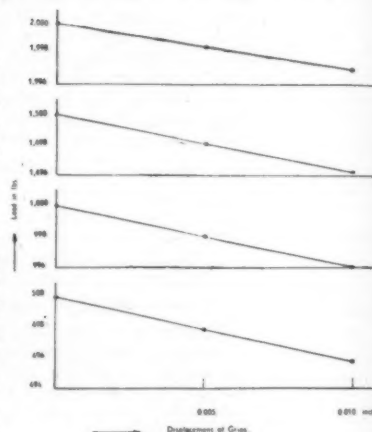


Fig. 39

change takes place in the load by an increase of the distance between the grips of about one-hundredth of an inch. At 2,000 lb. the load drops only by about 3 lb., at 1,500 lb. by $3\frac{1}{2}$ lb., at 1,000 lb. by 4 lb., and at 500 lb. only somewhat more than 4 lb. That means for the maximum initial load of 2,000 lb. the drop is only 0.15% and for the other loads only about 0.2%, compared to about 85% for the Baldwin machine in the same range and for the same displacement. Thus it can be seen that the difference between the two machines, based on quite different principles, is enormous. It is obvious that the duration of yielding period and the shape of the stress-strain diagram must be greatly influenced by the type of machine used. Fig. 40 represents, to the same scale, a comparison of the drop of the loads in function of the displacement of the grips for the four machines tested and this for a common initial load of 2,000 lb. This diagram makes it especially clear that practically there exists no drop of the load for the direct loading machine for a displacement of 0.01 in. between its

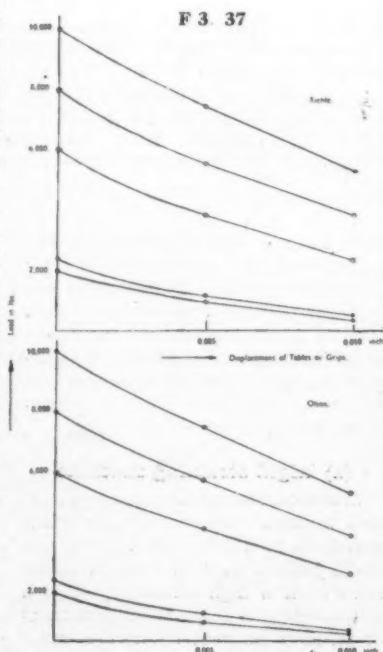


Fig. 38

grips, compared to the usual universal machines. For these machines the drop of the load is very appreciable, and amongst the rigid machines the Baldwin machine is the most rigid.

D—CONTROL TESTS OF THE MACHINES DURING OPERATION

(a) Worm-gear device

(1) *Rigid Straining Machine.*—In order to study the yielding effect under operating conditions, instead of provoking the yield-point under constant load as just described, the load was also increased continuously as it is in a

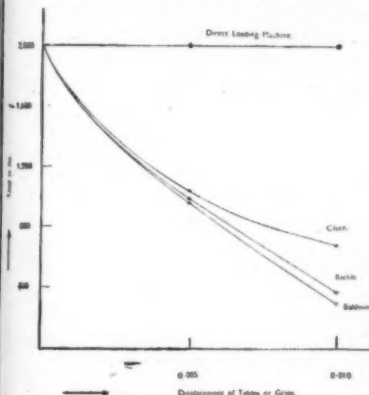
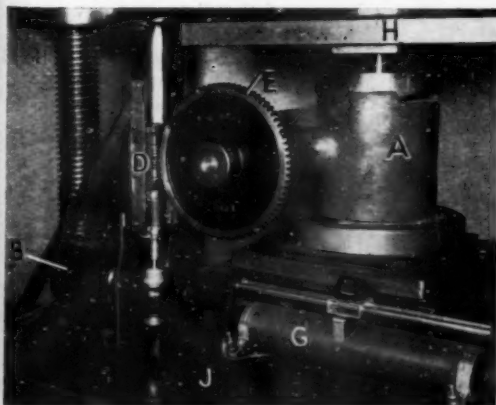


Fig. 40

normal tensile test. The sudden discontinuities observed in some load-deflection diagrams are not only due to the peculiar behaviour of certain metals and alloys, but are due, as already explained, to a greater extent to the testing machine itself. In order to obtain a few more facts about these questions, the following control tests of the rigid straining machine were made during normal operation of the

Fig. 41

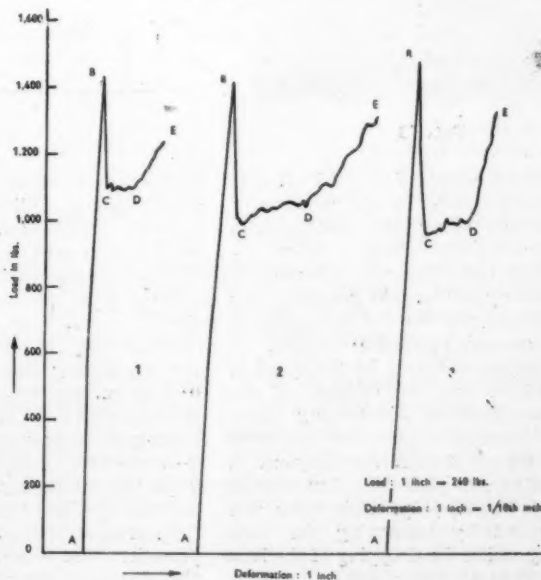


machine. For this purpose the device A of Fig. 36 placed between the loading tables of the Baldwin machine and operated by hand under static loads, was, according to Fig. 41, put into movement by an electrical reduction motor B, while the machine was in operation. Two worm-gears C-D drive under variable speeds the gear E adjusted on the axis of another worm-gear placed inside the device A. According to the speed of the gear E, regulated by the resistance G, the loading points H and I of the tables or the grips of the rigid machine can easily be changed in fairly wide limits during the loading operation of the machine. Thus, for instance, by a slow rotation of the wheel E during the first loading period the initial straight portion of the stress-strain diagram can be reproduced, the slope of which represents the Young's modulus of the "material" under test. Thus, a "stress-strain" diagram is obtained without the use of a test specimen and a straight line representing the elastic range of the load-deflection diagram can be recorded under normal operation of the machine. If under a certain load the motor is driven appreciably faster by reducing the resistance G, then the curious phenomenon of the load falling down from an upper to a lower limit can be artificially obtained; the same characteristic diagram concerning the sudden decrease of the load of the machine under operation, as for mild steel, for instance, can be easily

retraced. Furthermore, by an intermediate speed of the motor the lower yield-point can also be recorded artificially in the load-deflection diagram.

In Fig. 42 are shown three diagrams made with a machine under normal operating conditions. The increase of the load was about 400 lb. per min., so that this value represents an average loading speed frequently used in testing practice during the elastic period. The elastic strain in the massive device A (Fig. 41) is so small that it is not indicated in the diagram A-B (Fig. 42) recorded by the machine. The line A-B showing a certain slope and representing the elastic deformation of the test specimen can, however, be obtained by a small and continuous diminution of the distance between the loading points of the machine during the increase of the load. By a speed of about 60 r.p.m. of the worm D, a slope of the line A-B corresponding roughly to that of an ordinary stress-deformation diagram can be recorded. A change between the loading points of about 0.3 in.-0.4 in. during the loading process is represented by a slope of the diagram A-B. If, however, at a certain load this speed (about 60 r.p.m. of the worm-gear D) is increased about double, then, curiously, the load of the running machine no longer increases. On the contrary, it falls down rapidly to a smaller value, and this takes place without any change in the position of the control valves of the machine.

Fig. 42



Thus is observed a phenomenon nearly identical to that recorded with mild steel and represented in the stress-strain diagram by an appreciable dropping of the load from an upper limit to a lower one. This means that during the first period of yielding the speed of deformation of the material, or, more correctly, that of the grips of the machine is not very high. About twice the value of the straining speed used in the elastic period to obtain the slope of the diagram is sufficient to provoke the dropping of the load of an appreciable amount. This seems to be an interesting fact, because we are not yet very well informed either about the amount of the straining which is necessary for the drop of the load nor about the speed with which this drop takes place. Moreover, the amount of

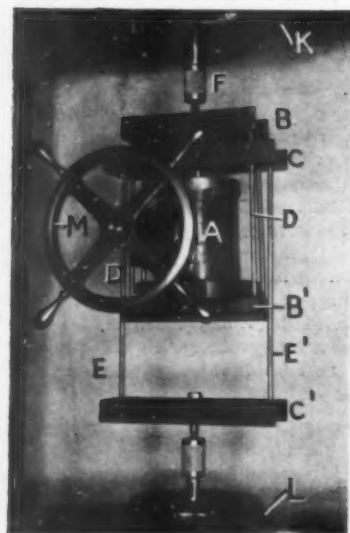


Fig. 43

strain necessary to obtain this effect is easy to calculate by the number of revolutions taking place and the ratio between one revolution of the worm-gear and the difference in length of the loading points. The gear E having 80 teeth, one revolution means a difference in length of 0.00027 in. It can also be evaluated by the speed of the motor and the change of the distance between the loading tables that the drop from the upper to a lower load (about 350 lb. for diagram 1, Fig. 42) takes place in a few seconds (about 3 secs.) only. This value was controlled by measuring the time during which the dropping of the load from B to C takes place.

In order to keep the load nearly constant at its lower value, the speed of the motor was again changed and was, during the period C-D, an intermediate one between the phase A-B and the yielding period B-C. With about 72 r.p.m. of the worm, the load did not change appreciably during a longer period, and the horizontal part of the diagram C-D was obtained corresponding to the deformation at the lower yield-point.

For a further very small reduction of the speed of the motor to 68-70 revolutions, the load again started to increase in function of the increase of the distance between the loading tables (D-E, Fig. 42). Thus the artificially recorded diagram A-B-C-D-E, easy to control and to reproduce,

from those of diagrams Nos. 1 and 2.

In order to get more reliable indications about this basic point, the rate of the load increase and of the dropping of the load from an upper to a lower limit were, in another series of tests, controlled by the automatic time recorder described in part B. For this experiment the device A (Fig. 36) was not placed between the loading tables of the machine working under direct compression loads; for this test the device A was suspended between the grips of the machine as shown in Fig. 43. By a special arrangement composed of two sets of cross-pieces B-B' and C-C' as well as bolts D-D' and E-E' the tension forces acting upon the device A were changed into compression forces. Furthermore, the

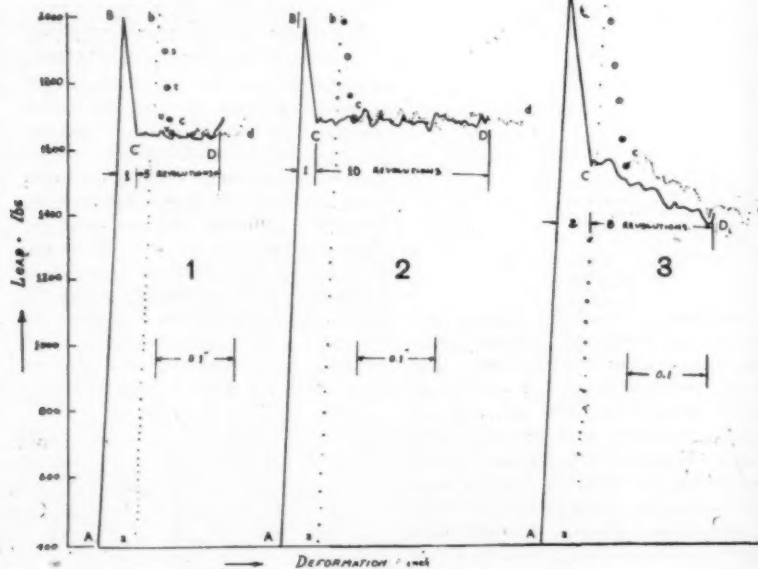


Fig. 44

represents approximately the principal phases of an ordinary stress-strain diagram of mild steel. Diagrams No. 2 and 3 represent analogous results obtained nearly under the same conditions. The loading rate was also about 400 lb. per min., and the distance between the grips was increased during the tests by about 0.00027 in. per sec., giving the slope of the curve A-B of diagram No. 2. During the dropping period of the load C-D the rate of displacement of the grips was, with regard to A-B, increased by about 50%, provoking a drop of about 400 lb. This drop took place in about 3 secs. For diagram 3 these values were not very different

changes of the distance between the loading points F-G were recorded on the diagram by attaching the rollers immediately to the cross-pieces K-L. The diagrams recorded with this arrangement at different loading speeds are shown in Fig. 44. Diagram No. 1 was recorded under loading speeds of about 1,000 lb. per min., as also represented by the autographic time record a-b. By turning the hand-wheel M one complete revolution (equal to 0.021 in. displacement of the grips), which can be easily done in about 1 sec., the load dropped from the maximum of 2,000 lb. to about 1,650 lb. (B-C, Fig. 44, No. 1). It is interesting to note, and this seems a characteristic fact, that the drop of

the load does not take place as quickly as the change in length between the grips is executed. While this displacement could be done in about 1 sec., the drop of the load, according to the indication of the machine and the time-recording diagram, took place in a period of about 3-4 secs. This is shown in B-C of the stress-strain diagram and in the time record of the autographic diagram *b-c* (encircled points *s, t, u, v*, Fig. 44). Such a lag between these two operations, the change of length between the grips and the record of the machine seem to be due to the inertia of the load indicator and the recording devices. Furthermore, it may be interesting to observe that for this arrangement it was necessary to change the distance between the grips by about 0.021 in. in order to record about the same drop of the load (350 lb.) as in the arrangement shown in Fig. 36. It is evident that this latter arrangement is much more rigid or stiff as the compact device A is placed immediately between the massive compression loading faces of the machine. The arrangement for the tension tests described and shown in Fig. 43 is, however, much softer, due to the elastic deformation of the cross-pieces and the bolts under load (about $\frac{1}{2}$ in. diameter and $1\frac{1}{2}$ in. long) necessary for this kind of attachment.

In order to keep the load at the same value after the initial loading took place (C-D in diagram No. 1) the hand-wheel had to be turned appreciably slower than in the dropping period. By five complete revolutions executed during about 60 secs., according to the chronometer *c-d*, the load of the machine regulated for about 1,000 lb. per min. did not change very much in this period; only variations from about 1,620 lb. to 1,650 lb. were recorded. The main diagram A-B-C-D corresponds fairly well with the yielding record of mild steel, showing the upper load B, the characteristic drop of the load B-C and the lower yield period C-D (Fig. 44).

As the loading speed may have some influence on the drop of the load in the usual rigid straining machine, diagram No. 2 was made with much higher rates of loading. It is interesting to note that for a loading rate of 2,400 lb. per min. in the elastic range diagram No. 2 (Fig. 44) is very similar to No. 1, recorded at the loading rate of 1,000 lb. per min. The only perceptible difference is in the time record *a-b*, which shows during the initial loading period an increase of the load of about 40 lb.

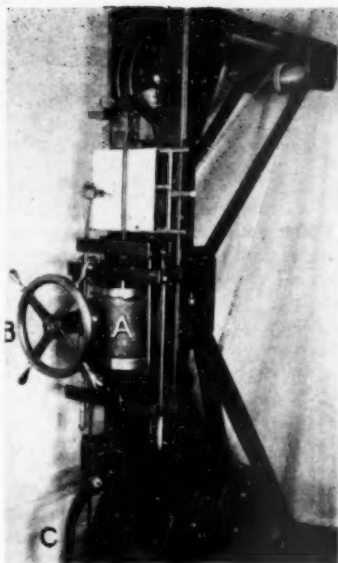


Fig. 45

per sec. In spite of this fairly high load increment, the dropping B-C took place as for diagram No. 1 in about 3-4 secs., as shown by the time diagram *b-c*. It seems, however, that the obtained minimum loading period C-D is for this experiment in its average value somewhat higher (about 1,680 lb. compared to 1,630 lb. for diagram 1). The distance C-D represents a difference in the loading points of 0.21 in. (10 revolutions of the hand-wheel) executed during about 110 secs. (diagram *c-d*). Diagram No. 3 represents the results of a test executed with a still higher load increment of about 3,400 lb. per min., according to the time record *a-b*. Here again the dropping of the load takes place in about the same period as for diagrams Nos. 1 and 2, taking into consideration that the displacement of the loading points was the double of that of the first two tests, as the hand-wheel was turned twice. The load dropped by an amount somewhat less than twice (550 lb.) that of the first two experiments Nos. 1 and 2. The time for this dropping of the load was about 5 secs. (*b-c*).

(2) *Direct Loading Machine.*—It is obvious that the direct loading machines, based on a very simple principle for loading and straining the test specimens, are much easier to control and their results are also easier to interpret than those of the complicated rigid straining machines. If the device A (Erichsen tester) is placed

in the direct loading machine as described previously for a rigid straining machine and as represented in Fig. 45, the diagrams, recorded with this machine under operating conditions, will be quite different from those of the rigid type machine. Here also a small and continuous increase of the distance between the cross-heads of the machine, by turning slowly the hand-wheel during the loading operation, produces the slope in the first period A-B of the stress-strain diagram, as shown in Fig. 46. If, in point B, the wheel is turned as fast as possible, the load does not decrease at all, but remains almost constantly at the same value during the period B-C; as already shown, an increase of the length between the grips of the machine does not affect or has only a very small influence on the actual load recorded. By the chosen speed of the hand-wheel B and the loading speed of the machine regulated by the crank C, the part B-C of this diagram will be completely horizontal without any change in the load; it can also fall slightly, as shown in B-D, if the speed of the hand-wheel is very high and simultaneously the load is increased only in a very small proportion. Usually, however, for a normal speed of the hand-wheel (one revolution per second) and a normal loading speed (about 500 lb. to 1,000 lb. per min.), the diagram shows, between B and C, the tendency of increasing load, according to B-C'; It is not possible to obtain with this machine under similar conditions the characteristic diagram of the rigid straining machine with a sudden and steep drop of the load from an upper to a lower value.

This test on the direct loading machine confirms the theoretical deduction in part A of this work. This means that, according to Fig. 1, the way in which yielding of the material takes place is principally dependent on the machine used for the test. The characteristic drop of the load occurs only in rigid straining machines. However, a completely different effect is obtained in the direct loading machine as shown in Fig. 46.

(b) Frictional sliding device

An additional control of the two principal types of testing machine in operation was made under different testing conditions. In general, the worm-gear device permits a change in length between the loading grips of the machine responding more or less to static testing conditions. However,

it is not possible to obtain with this device an instantaneous change between the loading grips. On the other hand, the yielding of most metals showing an upper and lower limit takes place always under dynamic conditions and this in an excessive short time. This means that the characteristic yielding process is a phenomenon which appears instantaneously. Hence it is also necessary to study the behaviour of the testing machines under this condition. For this purpose the frictional sliding device described in B-*d*) was used in both machines, producing an instantaneous artificial yielding. By this

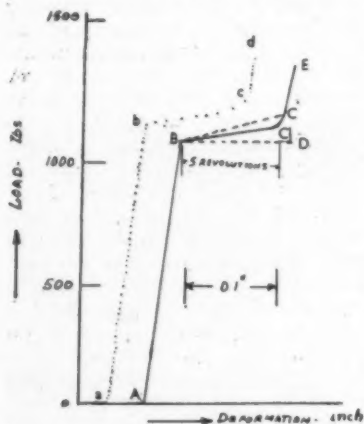


Fig. 46

device the characteristics of the testing machines could be controlled dynamically under nearly identical conditions as those produced by the yielding of the test specimen. The control of the machine by using an artificial yielding has furthermore the great advantage that the results are completely independent of occasional irregularities of the material tested, which, as generally known, are appreciable and cause a great deal of trouble in the usual testing technique. There does not exist two individual bars of material showing exactly the same behaviour, and the same results during the yielding period. Test specimens machined out of the same bar may have different characteristics regarding the upper and the lower yield-point. It is very hard to separate the individual characteristics of the test specimens from those of the machine. However, by using the frictional sliding device all tests are reproducible an unlimited number of times with exactly the same results concerning

these critical loads. Besides this, this testing method is based on the non-destructive principle; this can be mentioned as further advantage for its use in this work.

(1) *Rigid Straining Machine.*—The first test made on the rigid testing machine in operation executed with the frictional sliding device was completely successful in so far as the results expected were fully obtained. Fig. 47 shows the first stress-strain diagram recorded with this device. The cord extensometer was fixed for this test series between the loading tables of the machine. The part A-B of the diagram represents the elastic deformation of the specimen, while part B-C shows clearly the first period of the yielding phenomenon of, for instance, mild steel. At a load of 2,400 lb. the characteristic drop from a higher to a much lower limit, in this case about 1,725 lb., takes place. This appreciable decrease of the load, indicated in the diagram, is recorded in a very short time, corresponding to about 1 sec.; the phenomenon itself in the sliding device is, however, instantaneous (less than $\frac{1}{100}$ of a second); this excessively fast sliding is accompanied by a very audible and sharp crack between the friction plates. The first slip is, moreover, extremely small; due to the rigidity of the machine and the very small sliding distance between the grips, the sliding process starting at point B is stopped immediately at a lower load at C; After this first sliding period, the valves of the machine being left open, the load at C starts again to increase in the same manner as for A-B. This time it does not reach the same maximum load at B. Already at a much lower load of about 2,000 lb. this characteristic sliding process takes place again; the load difference D-E between the maximum and minimum values being this time much smaller than the initial sliding period B-C. After these first two sliding movements in the machine, further sliding steps F-G, H-I, etc., continue to arise regularly between almost identical maximum and minimum loads. This sliding phenomenon can be repeated as long as the free space of the device is not exhausted. For this diagram a somewhat more than one-half of the whole possible displacement between the plates was used. The whole free displacement between the plates being of the order of about 210-1000 in., and the distance being covered in about 35 to 50

steps (depending on the rigidity of the machine and the range of the load) with maximum and minimum loads, each step represents an effective sliding between the platens of about $\frac{1}{1000}$ in.

In general, it may be said that this diagram shows in its three phases characteristics nearly identical to the stress-strain diagram of mild steel with its elastic deformation phase A-B, its upper yield-point B, its inexplicable drop of the load B to a minimum limit C, and finally the irregular yielding at the lower unstable loads D-E to Y. Even the phase of regularly increasing loads after sliding takes place, can be reproduced by this device. Here also

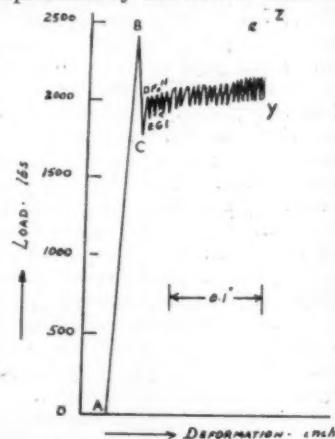


Fig. 47

the load increases regularly after yielding between Y and Z when the free sliding distance of the plates is exhausted. As this device permits obtaining these records on the machine under normal operating conditions, that means under constant but different loading rates and a sudden dynamic sliding effect in the yielding point region, the results can be considered as fully reliable in throwing light on the very complicated yielding phenomenon of metals. A clear separation of the yielding characteristics of the test specimen from the effects of the testing machine in operation is now possible, so that a more detailed study of the very strange yielding phenomenon can be undertaken with some prospect of reliable results concerning the important part which the testing machines themselves take in this curious process. As this testing method seems of fundamental importance for further investigation, a few other tests to control these first results were undertaken with this device. Diagram No. 1 (Fig. 47)

To be continued.

MICROCHEMISTRY

APPARATUS • METALLURGICAL APPLICATIONS • TECHNIQUE

IN general, the tendency seems to be to classify chemistry broadly into the three main groups of Inorganic, Organic and Physical, with a few subsidiary appendages. This rule is fairly rigidly applied to the teaching of chemistry. But thereby one overlooks certain other possible fundamental classifications. Dividing the activities of the class "chemist" with like precision, one finds that they fall naturally into three equally well-marked categories; synthesising, analysing and measuring. The last-mentioned class can be identified roughly with the physical chemist. But the organic and inorganic chemists seem, on the face of it, to be as likely to spend their time in analysis as in synthesis. To give one of these prior importance is as invidious as distinguishing in order of appearance between the fowl and its ovoid forebear-offspring. Now at present there exists Professorial Chairs in the three customarily accepted branches of chemistry; though usually there is a questionably logical fusion of Inorganic and Physical chemistry. But in this country there is a lamentable lack of higher posts for the teaching of Analytical chemistry. It is not even given the dignity of a half-Chair; the lectureships assigned to it are few. It is not unreasonable to query the wisdom of this policy. A School of Analytical Chemistry—even a School of Inorganic and Analytical Chemistry (since ninety-one elements may be presumed to produce a greater variety of techniques than one element) would surely prove no inconsiderable attraction to many chemists equally vital, to many of the younger generation of would-be chemists.

Desiccants in Microchemical Analysis

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It is frequently difficult to decide on an appropriate desiccant for any particular operation, and critical comparisons of the properties of the many available desiccants are difficult to find. In this paper a wide selection of desiccants is discussed with reference to their specific applications.

DESICCANTS, or dehydrating agents, if that term is preferred, find application in microchemical analysis, as absorbents for water in the trains used in the determination of carbon and hydrogen in organic compounds, fuels and the like, as well as in the determination of water. Their use in desiccators needs little comment.

The agent used originally as an absorbent for water in the combustion train designed for the determination of hydrogen and carbon in organic compounds was phosphorus pentoxide. Due to trouble caused by the nature of the product formed by the action of moisture on the phosphorus pentoxide, the solid was mixed with glass wool before use by Kemmerer and Hallett,¹ whereas Boetius preferred to mount the pentoxide on 10–20 mesh pumice.² The use of "dehydrite" was advocated by Kirner for the absorption train in the micro-determination of carbon and hydrogen in organic compounds³ and in fuels.⁴ Later, this worker resorted to the use of "drierite" for the determination of oxygen in organic compounds.⁵ "Anhydron" is now the

desiccant in most common use in micro-combustion trains; Kirk and McCalla used "anhydron" in 1932 for this purpose.⁶ Belcher and his colleagues have used "anhydron" in all their micro-combustion methods for the determination of carbon and hydrogen in organic compounds and fuels.^{7, 8, 9} Micro-methods for the determination of carbon in steel also rely on the use of this desiccant.

The determination of water can be carried out either directly, by obtaining the increase in weight in an absorption tube packed with a desiccant, or by an indirect method; as an example of such a method, Belcher¹⁰ determines water in charcoal, coal, coke and mine dusts, by passing nitrogen, dried by passage through either "anhydron" or activated alumina, over the weighed sample heated to 110° C. in a heating block, the loss of weight in the sample being due to the removal of water.

The comparative efficiencies, capacities, modes of action and so on, of the various desiccants, common and less common, have been compared by various

¹ Kemmerer and Hallett, *Ind. Eng. Chem.*, **19**, 173, (1927).

² Boetius, *verlag Chemie*, Berlin, 1931.

³ Kirner, *Ind. Eng. Chem.*, An. Ed., **6**, 358 (1934).

⁴ Kirner, *Ind. Eng. Chem.*, An. Ed., **7**, 294 (1935).

⁵ Kirner, *Ind. Eng. Chem.*, An. Ed., **9**, 193 (1937).

⁶ Kirk and McCalla, *Mikrochemie*, **12**, 88, (1932).

⁷ Belcher and Smith, *Fuel in Science and Practice*, **19**, 183 (1940).

⁸ Belcher and Spooner, *J.C.S.*, 1943, 313.

⁹ Belcher, *Chem. and Ind.*, ix, 605 (1941).

¹⁰ Belcher, Private communication.

workers, and it has been considered desirable to collect these data in the present paper, to assist the analyst in choosing the desiccant suited to his particular set of conditions. Many of these desiccants still await rigid testing in combustion trains.

A very useful summary of the various bases of classification of desiccants has been drawn up by G. F. Smith¹¹ :—

A.—General Classification :

1. Regenerative and non-regenerative.
2. Chemical absorption and Physical absorption.
3. Co-ordinate covalence absorption and primary valence absorption.

B.—Specific Classification¹² :

1. Anhydrous or partially dehydrated salts which absorb water to give solid products.
2. A solid which absorbs water to give a saturated solution.
3. A liquid which absorbs water to give a solution of low vapour pressure.
4. Adsorption drying agents which hold water by capillary attraction phenomena.
5. Metals and alloys absorbing water through its decomposition to form hydrogen.

C.—Comparison of group characteristics :

1. Drying power—intensity or efficiency.
2. Drying capacity.
3. Drying speed—velocity of dehydration.
4. Temperature range of drying at maximum efficiency.
5. Conditions under which regeneration is most efficient.

From the point of view of the analytical chemist, the group characteristics are, of course, the most important. It is not, by any means, universally understood what differences exist in drying power, speed and capacity between the various desiccants in common use. Indiscriminate use of desiccants may cause grave inaccuracies. Air passed through one desiccant may lose a further amount of moisture on passing through a second, but may take up water from the desiccant itself on passing through a third, depending on the relative drying powers of the three. Again, one desiccant may be more efficient than another if the gas flow is slow, but less efficient if the rate of flow is increased. Further, one desiccant may lose its efficiency after absorbing far less moisture than can be efficiently retained by another.

The most useful quantitative valuation of the drying efficiencies of desiccants was made by Bower.¹² As a result of extensive tests, he arrived at a series of values for residual moisture per litre of the air dried by the desiccant at 30.5° C. These values can conveniently be grouped as follows, the reagents being placed in order of efficiency :

Group 1.—Less than 0.005 mg. of water per litre :

Phosphorus pentoxide.
Barium oxide.
Anhydrous magnesium perchlorate.
Calcium oxide.
Anhydrous calcium sulphate.
Aluminium trioxide.

Group 2.—0.01 to 0.02 mg. of water per litre :

Potassium hydroxide.

Group 3.—0.02 to 0.03 mg. of water per litre :

Silica gel.
Magnesium perchlorate trihydrate

Group 4.—0.1 to 0.3 mg. of water per litre :

Dehydrated calcium chloride.
Sodium hydroxide.
Anhydrous barium perchlorate.
Zinc chloride.
"Anhydrous calcium chloride."
Granular calcium chloride.
Anhydrous copper sulphate.

The chemicals used in these tests were the commercial products marketed as desiccants. In certain cases, some preliminary treatment was given : Calcium oxide was heated to 600–650° C. for four hours and cooled in a desiccator over barium oxide before use. Anhydrous calcium sulphate was heated at 220–230° C. for two hours while passing through it air dried by phosphorus pentoxide. The aluminium trioxide was heated for six hours at 150–180° C. while passing through it air dried by phosphorus pentoxide. Silica gel was heated to 110–130° C. for five hours *in vacuo*. Dehydrated calcium chloride was prepared by heating granular calcium chloride to 250–275° C., passing air dried by phosphorus pentoxide through it, and then passing dry carbon dioxide through it to neutralise any basic compounds ; the so-called "anhydrous calcium chloride" was found to correspond roughly to the formula $4\text{CaCl}_2 \cdot \text{H}_2\text{O}$. Anhydrous copper sulphate was heated to 250° C. for two hours, while passing through it air dried by phosphorus pentoxide.

A consideration of the above grouping will show that only those in Group 1 can be classed as final desiccants, while those in Group 4 are not to be classed as anything more than preliminary moisture removers. Those in Groups 2 and 3 are suited for use as preliminary driers, to be followed by one of the Group 1 reagents. This is good practice, since in this way the major proportion of the moisture is absorbed by the less efficient (and, in general, the cheaper) desiccant, leaving the more efficient agent to absorb only a small amount of moisture and thus retain its maximum efficiency for a much longer period.

No such comprehensive study of the drying speed or capacity has been made, and only a few figures are available. Further data can best be presented by a consideration of the various desiccants individually.¹³ Trade names given to various of these are somewhat confusing—they are included for reference.

Calcium chloride is still considered as the universal dehydrating agent in some circles ; this is remarkable when its efficiency is compared with that of the other well-known reagents. It is available in two forms : granular and fused. The granular form is prepared by heating the dried chloride ; it usually contains some water, and reacts alkaline, due to the production of free lime decomposition during heating. The fused chloride is a slightly more efficient desiccant, but also reacts alkaline—usually more so than the granular form. This alkaline reaction creates difficulties if the reagent is to be used in the train for the determination of carbon by combustion, as some carbon dioxide reacts with the lime present. In addition, "ascarite" (which is a form of sodium hydroxide mounted on asbestos), the usual absorbent for carbon dioxide, is itself a more efficient desiccant than calcium chloride ; gases dried by calcium chloride, on passing through "ascarite" are thus liable to have further moisture removed from them. The use of calcium chloride in desiccators must also be strongly condemned. Ignited residues of such substances

¹¹ "Dehydration Studies," G. F. Smith. Published by the G. F. Smith Chemical Co.

¹² Bower, Bur. of Stands., J.Res., 12, 241 (1934).

¹³ "The Chemical Analysis of Iron and Steel," Lundell, Hoffman and Bright, p. 24.

as aluminium oxide or calcium oxide are far more efficient desiccants than the calcium chloride. The result is, naturally, that the alumina or calcium oxide will tend to absorb water from the calcium chloride, just the reverse of the desired conditions. Calcium chloride cannot be used for drying ammonia, due to the formation of complex amines. A further disadvantage of calcium chloride is that it is considerably less efficient at 30° C. than at 0° C.; so much so that difficulties are likely to be encountered if different parts of an absorption train differ in temperature by more than a few degrees.¹⁴

A better desiccant of relatively low efficiency is anhydrous barium perchlorate, which is often termed "Dessichlor." It will absorb about 15% of its own weight of water (approximately the same as calcium chloride), is more efficient at room temperature than calcium chloride and can be regenerated without decomposition by heating to 400° C.

Hydrated magnesium perchlorate, or "Dehydrite"¹⁵ is a convenient preliminary desiccant. It is capable of absorbing about 15% of its own weight of water and is neutral in reaction. Its efficiency, however, falls fairly rapidly with temperature increase.

Silica gel¹⁷ is a useful desiccant of medium efficiency. Its great attraction lies in the fact that it can be regenerated repeatedly. It is obtainable commercially in an indicating form impregnated with a cobalt salt; this colours it blue until it becomes saturated, when it changes to pink. If the pink form is heated for some hours in the air oven it changes to blue, and the silica gel is ready for re-use as a dehydrating agent.

"Hydralo," or activated alumina,^{18, 19} a form of aluminium oxide containing about 10% water, prepared at a low temperature, is stated to be as efficient as phosphorus pentoxide with a slow gas flow. When spent, it can be regenerated by heating it, contained in a tube through which air dried by phosphorus pentoxide is passing, using a smoky flame. Providing activated alumina proves as reliable an absorbent as the conventional dehydrating agents, it appears to have the advantages of its absorptive capacity, ease of regeneration (eliminating the repacking of absorption tubes and thus minimising breakages) and its reputed efficiency. It is marketed in an indicating form, which changes colour when saturated with water.

Anhydrite, anhydrous calcium sulphate, also known as "Drierite," is an efficient regenerative dehydrating agent which has found some application,²⁰ but does not seem to have become popular. It can be obtained in an indicating form. Its absorption capacity is somewhat low; it will only absorb 6.6% of its own weight of water.

Calcium oxide is useful for drying ammonia gas; almost all other desiccants react with ammonia. If pure, the oxide has a much greater efficiency than if small impurities of silica and alumina are present; these impurities tend to form a glaze on the surface, during the preliminary ignition, and this considerably lowers the absorptive properties of the oxide.¹² The chief disadvantage associated with calcium oxide as a

desiccant is its affinity for carbon dioxide, which precludes its use in a combustion train.

Concentrated sulphuric acid was used by Bower¹² as a final absorbent, as was phosphorus pentoxide, indicating that it was found to be a better desiccant than barium oxide, which left a residual moisture content of 0.000065 mg. of water per litre of dry air. Other figures, however, indicate that the residual moisture content is higher; Baxter and Warren²¹ give a figure of 0.003 mg. per litre at 25° C. Nevertheless, it is a very efficient desiccant and its efficiency remains almost constant over the temperature range -25° C. to 25° C. A litre of air passing through pure sulphuric acid takes up only 0.003 mg. of sulphur trioxide,²² though commercial acid may contain excess sulphur trioxide in the form of pyrosulphuric acid. Before use as a desiccant, this should be converted to sulphuric acid by the addition of a small amount of water. Any dissolved sulphur dioxide or carbon dioxide in the acid can be removed by passing a current of dry air through the acid. Its absorption of water naturally dilutes the acid, with a consequent falling off in the efficiency of dehydration. This is not very serious, however, as acid of 95% strength is still more efficient than calcium chloride.²³ One of the chief disadvantages of the use of sulphuric acid is its physical state. It is inconvenient to include a liquid, especially one with highly corrosive properties, in a weighed system or a desiccator.

Phosphorus pentoxide is probably the most efficient desiccant. The usually accepted value for the residual mixture, after drying with phosphorus pentoxide is 0.000025 mg. per litre²⁴ (at 25° C.). Bower¹² showed it to leave a residual moisture content of less than 0.000065 mg. per litre at 30.5° C. It is not attractive to use, however. It forms a viscous liquid, which tends to block the gas flow and lead to channels. This may be prevented by packing between layers of glass wool, but the most effective method is to use a preliminary desiccant of lower efficiency.

Anhydrous magnesium perchlorate, "Anhydrone,"^{11, 16} is usually considered to be the best all-round desiccant. It has almost the same efficiency as phosphorus pentoxide when the gas flow is under 5 litres per hour and is relatively efficient at much more rapid flow rates. It is as efficient at 135° C. as at room temperature. It can be reactivated by heating *in vacuo* at 225-250° C. It will absorb 30% of its own weight of water at maximum efficiency. It does not become sticky on handling and, as it actually contracts slightly on absorbing moisture, does not form blocks or channels in use. It can be used for drying gases such as chlorine, hydrogen chloride, hydrogen sulphide, etc., as it has a neutral reaction. It cannot, however, be used for drying ammonia gas, since this is quantitatively absorbed, up to 225° C., with the formation of amines.

Barium oxide²⁵ is an efficient desiccant, with an absorption capacity of about 11% of its own weight. It is cheaper than magnesium perchlorate, but swells considerably on absorbing moisture. It can be used for drying ammonia, and also shows a considerable efficiency as a desiccant at temperatures above those at which other agents are useless.

¹⁴ Dibbitts, *Z. Anal. Chem.*, **15**, 121 (1876).

¹⁵ G. F. Smith, *Chemist Analyst*, **17**, 21 (1928).

¹⁶ Willard and Smith, *J.A.C.S.*, **44**, 2255 (1922).

¹⁷ Miller, *Chem. Met. Eng.*, **23**, 1155 and 1219 (1920).

¹⁸ Johnson, *J.A.C.S.*, **34**, 911 (1912).

¹⁹ Barnitt, Derr and Scripture, *Ind. Eng. Chem., An. Ed.*, **2**, 355 (1930).

²⁰ Hammond and Withrow, *Ind. Eng. Chem.*, **25**, 653 (1933).

²¹ Baxter and Warren, *J.A.C.S.*, **33**, 340 (1911).

²² Morley, *Z. Anal. Chem.*, **24**, 511 (1885).

²³ Dover and Marden, *J.A.C.S.*, **39**, 1609 (1917).

²⁴ Morley, *J.A.C.S.*, **26**, 1171 (1904).

²⁵ Smith, *Ind. Eng. Chem., An. Ed.*, **2**, 12 (1930).

One desiccant, probably more of interest academically than otherwise, is boric oxide.²³ If the reagent is prepared by heating boric acid to 800° C., pouring into carbon tetrachloride at 0° C., and then powdering, it is claimed that it is capable of absorbing about 25% of its own volume of water, at an efficiency greater than that of calcium chloride, provided that the gas flow is less than 2 litres per hour. It must, however, absorb some water to reach maximum efficiency.

A summary of the conditions calculated to give the best results from the use of desiccants will be a useful conclusion.

The desiccant used should be chosen with due consideration of the required efficiency of desiccation, bearing in mind all the other relevant factors. As

26. Walton and Rosenbaum. *J.A.C.S.*, **50**, 1648 (1928).

regards the use of desiccants in desiccators, the importance of this point cannot be too highly stressed.

Desiccants should be renewed regularly to ensure that their efficiency is maintained. This is also most important where desiccants are used in desiccators, as it is easily overlooked.

In an absorption train, whatever desiccant is used as the final absorbent for water should also be used in the preliminary purifying train, and should be the most efficient desiccant used in the train.

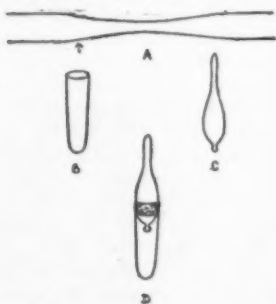
If carbon dioxide is also to be determined by absorption in "ascarite," a layer of the final desiccant used in the train should be packed into the carbon dioxide absorption tube, to ensure retention of all water, since "ascarite" is a less efficient desiccant than that used for the removal of water.

Apparatus in Qualitative Microanalysis

By R. Belcher and F. Burton

II. The Feigl-Krumholz Gas Reaction Apparatus

IN earlier contributions to this section,^{1, 2} the device we have termed "the spoon" (used for carrying out evaporations, certain confirmatory tests and the complete separation of the alkaline earth group) was described. A simple method for making this apparatus was given, which can be readily learned by students possessing little glass-working experience. It is perhaps not generally realised that other more conventional apparatus used in qualitative analysis can be made as readily, and its manufacture forms a useful part of the training of students taking a microchemical course. The difficulty in obtaining such apparatus from supply-houses at the present time is a further reason for providing an alternative source of supply.



Feigl and Krumholz³ have described an apparatus, the form of which is similar to the final form shown in the diagram at D, used for testing the gaseous products of a reaction. The substance to be tested is transferred to the bottom of the vessel. If it is a solid we have found the most convenient method to prevent sticking to the

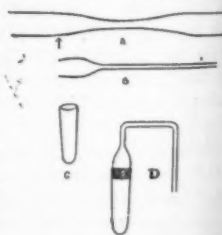
walls is to take a fragment up in the end of a fine capillary through which a solid glass thread will just slide. The material is then extruded on the bottom of the vessel. This same device is used, of course, in the determination of molecular weight by the Rast method. A drop of suitable reagent is placed on the knob of the apparatus and after adding acid or other suitable reactant to the test substance the stopper is inserted. The liberated gas will then react with the reagent on the knob. As an example of its application it is used to

test for carbonates, fluorides, chlorides, etc. by utilising well-established reactions.

A piece of glass tubing about 8 mm. diameter is drawn out as shown at A in the diagram. A file mark is made at the point shown by the arrow and a tiny flame from a piece of glass tubing, drawn out to a capillary and connected to the gas supply, allowed to impinge on the notch until a crack forms. The crack is then led round the tube by the flame, the edges ground smooth by rubbing on a glass plate with a paste of carborundum powder and water, and the drawn-out part cut and sealed as shown at B. A piece of suitably sized rod is drawn to the shape shown at C and ground to fit the tube by placing a paste of carborundum powder and water on it and rotating it carefully in the mouth of the tube until a good joint is obtained. Some little practice is necessary to make the tapering of the stopper correspond with that of the tube but it presents no difficulty after a few attempts.

III. Distillation Apparatus

FOR carrying out reactions where products of distillation are tested Feigl¹ recommends the apparatus shown in the diagram at D. The receiver can be either a micro-crucible or a centrifuge cone. The apparatus is useful, for example, in carrying out the chromyl chloride and other similar tests. It can be made as follows. A piece of tubing 8 mm. in diameter is drawn out as shown at A in the diagram. It is then cut and treated as described in a previous article² to give the tube shown at C. Another piece of narrower tubing is drawn to a long capillary as shown at B, and drawn sufficiently at the other end to give a slight taper corresponding to that of the reaction tube. It is then smoothed and ground into the latter as described in earlier articles. Finally the capillary is bent to the shape shown to give the final form of the apparatus.



1 R. Belcher. *METALLURGIA*, 1944, September, 280.

2 R. Belcher and F. Burton. *METALLURGIA*, 1944, November, 42.

3 Feigl and Krumholz. *Mikrochemie, Pregl-Festschrift*, 1929, 83.

1 F. Feigl. "Spot Tests." Nordemann Publishing Co. Inc., N.Y.

2 R. Belcher and F. Burton. *METALLURGIA*. Note II, above.

Resistance to Deformation of Cold-Worked Steel

AN investigation has been carried out by F. Körber and A. Eichinger of the way in which resistance to deformation of carbon steels is changed through cold-working. They commenced by performing comparative tensile and compression tests, under equivalent conditions, using cylindrical test-pieces, 22.6 mm. in diameter and 35 mm. in length. The steels investigated had carbon contents of 0.04% (steel A), 0.12% (steel B) and 0.20% (steel C) respectively and were annealed in the normal way. In these experiments it was discovered that not only the modulus of elasticity but also the upper and lower yield points (tension and compression) had the same values under compression as under tension conditions. In addition, above the flow point there was agreement, within the accuracy of measurement, between the relevant true σ - ϵ lines for tension or compression on the respective cross-sections and on the respective lengths. When the true stress was kept constant the flow-range at the yield point was also the same for tension and compression. These results confirm the observation that, in the case of resistance to shear of metallic materials, the stress which is normal to the sliding surface is practically without influence within the limits here considered.

If, following plastic deformation, the stress is removed and reapplied in the reverse sense, there occurs the well-known Bauschinger effect, i.e., the limit of proportionality is very much lower in the second deformation. The position of the limit of proportionality in such cases is dependent to a great extent, as indicated by these graphs, upon the length of time during which the sample is held between the two deformations and, in fact, it rises with time. If test-pieces are deformed back and forth many times, the limit of proportionality lies essentially below the upper yield point of the metal at the start. This point in the case of the steels investigated always coincided with the limit of proportionality. For

greater extensions the resistance to deformation during the third and similar deformation exceeds that during the first. With increased time of retention between two deformations the limit of proportionality in the third deformation rises more quickly than that in the second. If the test-piece is held for a longer time after plastic deformation has occurred and is then deformed in the same sense the limit of proportionality lies above that found at the end of the previous deformation.

The effect of ageing on a material that has undergone plastic deformation is to induce a type hardening ("Härtung") which is very nearly equally great in all directions. This type can, therefore, be differentiated from the kind of hardening ("Verfestigung"), which occurs even in simple one-component systems, where the material shows itself as anisotropic with respect to its resistance to plastic deformation. Thus steel C, with 0.2% C, exhibits definitely more marked anisotropy of deformation-resistance after cold-working than does steel A, with 0.04% C, a fact which lines up with the greater susceptibility to ageing of the ingot steel with the lower carbon content. For this reason the more rapid closing of the hysteresis loop in the case of the steel with the

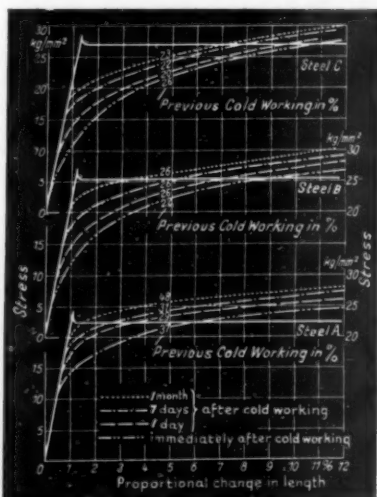
lower carbon content should not be taken as an indication of more rapid recovery. The latter is an effect which is in opposition to hardening and ageing alike, seeing that the changes which have been induced by plastic deformation are being reversed and the material is tending to return to its original state. Recovery is quickly effected by heating the sample below the recrystallisation temperature for a period the duration of which depends upon this temperature. It does not occur at room-temperature in the case of ingot steel even after long standing.

The possible reasons to be considered for the effect, noticed with all three carbon steels, A, B and C, in the normal state, of a definite upper yield point, coinciding with the elastic limit and accompanied by the falling-off of the load are:—

1. Collapse of anet-work of greater tenacity, possibly of the cementite grain boundaries.
2. Mosaic block structure.
3. Instability, perhaps due to a special orientation of the crystallite or, under certain circumstances, of the texture, or to something akin to delay in boiling.
4. Twin formation and phase change.
5. Alteration of stress in the slip planes.
6. Alteration of distribution of stress over the cross-section.

Of these No. 1 does not appear to be very likely because the collapse should take place earlier with tension than with compression, a conclusion which would not accord with the observation that with pure tension and pure compression the yield points are the same. In contrast with this, the explanation based on a mosaic block structure fulfils, in the opinion of Körber and Eichinger,* all the conditions. As against the third suggested explanation there is the fact that the upper yield points under equivalent test conditions prove to be practically constant and independent of time, an unlikely state of affairs if the equilibrium is unstable. Twin formation

* F. Körber and A. Eichinger: "Resistance to deformation of cold-worked steel." In *Mitt. K.-Wirtsch.-Eisenforsch.* Vol. 26, 3, Paper No. 450. Düsseldorf, 1943.



From *VDI Zeitschrift* Bd. 87 Nr. 45/46, 13th Nov., 1943, 733-4.

and phase change do not appear to be very probable reasons for the falling-off of load.

Regarding alteration of stress in the slip planes it is pointed out that strong elastic-plastic characteristic stresses must act on the boundary surfaces and a thicker bar should show a yield point about 15% higher than a thin bar of the same material, because of the transverse stress effects. Stress distribution in the pulled bar is considered

from the point of view that both the equilibrium- and yield-conditions can still be fulfilled if the distribution of stress is not uniform and accordingly a lowering of the supporting load is to be expected. However, it is still not regarded as impossible that the cross-section may be unaffected by non-uniform distribution of stress. It would appear questionable also how an explanation of the Bauschinger effect could be given on this basis.

cedure in which the time of load application was different. Diamond hardness tests were made on a Vickers hardness tester, using a 50 kg. load. Tensile tests were made on 2 in. gauge length specimens $\frac{1}{4}$ in. \times $\frac{1}{8}$ in. in section for the flats and 0.505 in. diameter for the round bars, and the load at fracture was noted so that true-stress-strain curves could be derived from the data. The rate of work-hardening was measured from those curves.

Hardness data for some of the alloys tested are given in Tables I and II. The hardness indentations of the sinking type are always associated with annealed materials of high work-hardening capacity, while the ridging type impressions are associated with cold-worked materials of low work-hardening capacity. Preliminary examinations of these data indicated that independent relationships based on the appearance of the hardness indentations could probably be applied, as in the case of the various hardness scales, but that additional data were required before suitable curves could be established.

The results obtained show, in general, that two details of testing procedure should be given further consideration before specific conversion relationships are developed, namely the control of the time factor in Rockwell tests and the influence of the tungsten-carbide versus ordinary and cold-worked steel balls in the Brinell test. Differences in work-hardening as measured by the Meyer n coefficient have a very great influence on hardness

Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell

By R. H. Heyer

IN a recent paper¹ the author presented data which served to outline some of the problems involved in hardness conversions. This work has now been extended to include tensile test results and standard Brinell tests. In the previous investigations, many of the test specimens were of sheet thickness, too thin for Brinell tests. While Brinell data obtained from Rockwell impressions made with a $\frac{1}{16}$ in. diameter ball illustrated certain features of Brinell compared with Rockwell and Vickers diamond hardness readings, they only approximated to standard 10 mm. ball Brinell results. Additional materials $\frac{1}{4}$ in. thick and also in the form of round bars have been tested.

All the new materials, which included cold-rolled copper, brass—both

cold-rolled and annealed, carbon steel—both cold-rolled and heat-treated, Alcoa alloy, 18-8 steel, Dowmetal F, as received and annealed, and silicon bronze as received and annealed, were tested at five or six loads to establish the Meyer hardness relation. All tests were made using a 10 mm. tungsten carbide ball and no impressions larger than 5.5 mm. diameter were made. The Brinell hardness at 3,000 kg. was determined from the Meyer relationships, however, if the diameter indicated by the extrapolated load-diameter line was less than 7.0 mm., Rockwell tests were made on Rockwell hardness testers calibrated against standard blocks, and the testing procedure recommended by the A.S.T.M. Standard Methods of Test for Rockwell hardness was followed. A second set of readings was made using a pro-

From Amer. Soc. for Testing Materials, June, 1944. Preprint No. 95, 18 pages.
1. METALLURGIA, 1944, Vol. 29, pp. 160-161.

TABLE I.—HARDNESS DATA FOR $\frac{1}{4}$ IN. FLAT-ROLLED MATERIALS.

Material	Vickers Kg	ROCKWELL HARDNESS												BRINELL HARDNESS				Meyer <i>a</i>	Meyer <i>n</i>	Type of Indentation.
		G Scale		B Scale		F Scale		45-T Scale		20-T Scale		15-T Scale		500 Kg.	1,500 Kg.	3 000 Kg.	<i>d</i> = 3.75mm.			
		A.S.T.M.	15 Secs.	A.S.T.M.	15 Secs.	A.S.T.M.	15 Secs.	A.S.T.M.	15 Secs.	A.S.T.M.	15 Secs.	A.S.T.M.	15 Secs.							
Copper, Cold-rolled ..	110	—	—	54.6	55.1	91.6	89.9	37.4	35.1	60.0	58.9	82.5	81.9	99	91.5	83	88.5	83	1.95	Ridging
Brass, Cold-rolled ..	189	—	66.9	—	90.6	—	108.1	—	65.0	—	76.1	—	89.5	174	180	178	177	127	2.095	Ridging
Brass, Cold-rolled, Annealed 455° C.	77	—	—	39.9	39.3	80.5	—	12.6	12.3	42.4	42.3	73.4	73.4	72	81	82.5	77	43	2.31	Sinking
Ingot-Iron ..	71	—	—	30.6	24.4	74.8	70.8	103.9	98.1	37.6	33.3	71.0	69.0	66	71.5	73.5	68.5	37	2.3	Sinking
0-18 C. Steel, Cold-rolled ..	223	76.4	74.9	96.0	95.2	110.8	110.5	68.0	67.4	79.8	79.2	91.7	91.4	204	207	207	202	166	2.0	Ridging
0-18 C. Steel, Cold-rolled, Annealed 925° C.	123	—	—	70.1	68.4	96.3	95.5	42.4	41.1	61.7	60.9	82.6	81.9	107	114.5	117	112.5	71	2.22	Flat
Alcoa 24 Steel.	146	46.9	46.6	77.7	77.2	100.8	100.7	50.8	50.2	68.3	68.1	86.2	86.0	130	139	144	139	88	2.185	Flat
19-5% Chromium, 9-5% Nickel Steel	163	53.4	50.9	80.0	77.9	100.9	99.5	49.1	46.9	67.0	65.0	84.8	83.8	121	134.5	145	136	71	2.35	Sinking

TABLE II.—HARDNESS DATA FOR ROUND BARS.

Material	Vickers Hardness 50 kg.	Rockwell Hardness B Scale A.S.T.M.	Brinell Hardness				Meyer <i>a</i>	Meyers	Type of Indentation
			500 kg.	1,500 kg.	3,000 kg.	<i>d</i> = 3.75 mm.			
Sicilian Bronze As received	242	101.1	222	222	223	224	165	2.08	Ridging
Silicon Bronze Annealed 290° C. ..	120	68.2	106	114.5	120	114	68	2.24	Sinking
Silicon Bronze Annealed 455° C. ..	80	38.0	71	83	89	78.5	35	2.44	Sinking
0.19 C Steel, Cold-rolled	181	90.2	175	170	167	170	136	2.00	Ridging
0.19 C Steel, Annealed 760° C. ..	126	70.4	110	114.5	114	114.5	78	2.13	Flat
0.19 C Steel, Annealed 925° C. ..	115	65.2	104	107.5	106	106.5	75	2.11	Flat
Dowmetal A as received	61.5	20.6	58.5	68.5	74.5	61	25	2.52	Sinking
Alcoa 51 Steel Ppt. at 150° C. ..	97.5	51.2	86.5	87	85.5	88	61	2.11	Ridging

and hardness-tensile strength conversion relationships. The marked difference in appearance of ball type hardness indentations depending on the work-hardening of the metal can be used to advantage in selecting conversion relationships of greater accuracy than those now available, but additional test data are required before those relationships can be made fully effective.

It was found that the 1,500 kg. Brinell test had advantages over the 3,000 kg. test in the hardness range under consideration because the size

of the indentations was more favourable and the effect of work-hardening capacity on the Rockwell-Brinell conversion relationship was greatly reduced for this particular conversion. It was also found from the standpoint of the experimental data obtained that the method proposed by Schwarz² for obtaining tensile strength from Brinell hardness tests made at two test loads was worthy of further study.

A testing procedure is suggested for obtaining hardness and hardness-tensile strength conversion data for specific materials.

2. O. Schwartz, *Forschungsarbeiten*, 1929, p. 313.

Effect of Time, Temperature and Prior Structure on the Hardenability of Alloy Steels

By J. Welchner, E. S. Rowland and J. E. Ubben

FIVE common S.A.E. type alloy steels were used in this investigation. The effect of five prior structures—namely, spheroidised, annealed, hot-rolled, normalised, and oil-quenched on Jominy hardenability over time intervals of 0, 10, 40 mins and 4 hours were explored. The effect of a range of quenching temperatures from 790° to 870° C. was determined on the annealed and normalised prior structures. End-quench curves for the different conditions were determined, together with summarising curves to show the effect of the several factors at Rockwell C 50 level (Rockwell C 37 for S.A.E. 4620 type steel). A few tensile and Izod impact values were also

obtained, showing the effect of prior structure on physical properties of S.A.E. 4140 and 4340 steels as related to the hardenability values. The types and compositions of the steels and the Brinell hardness of the prior structures of the various steels are given in Table I.

In the low-carbon alloy steel, time and temperature up to 10 mins. showed

a discernible hardenability increase only from the two coarser initial structures. Times beyond this interval as well as all periods on the faster cooled structures had no significant effect. A temperature of 790° C. was unsuitable for developing full hardenability with this composition, while temperatures in excess of 815° C. offered no advantage in obtaining better response to quenching. Steels in the medium carbon range reacted essentially alike. The prior structures of all the steels divided into groups affected by time and temperature and quenching temperature—i.e., spheroidised and annealed in one group and hot-rolled, normalised and quenched in the other. The spheroidised and annealed prior structures were very sensitive to the heating intervals used, yielding values far below normal, excepting at the shorter time periods, and this range was less for the alloyed type (N.E. 9442), and substantially greater for the higher alloyed types.

The rapidly cooled prior structures showed no important changes in hardenability over the time period investigated, except that steel S.A.E. 3240 for short-time intervals showed an increase in hardenability for the normalised and quenched prior structures, and steel S.A.E. 4340 showed a significant decrease for all the more rapidly cooled prior structures for a time period of 4 hours. This decrease was attributed to partial homogenisation of a banded structure. Among the higher alloyed medium carbon steels, the normalised prior structures produced higher hardenability at all quenching temperatures. With increasing quenching temperature, the hardenability of the normalised structure either quickly became constant or attained a maximum value and decreased slightly, while the annealed prior structure showed a steady increase with quenching temperature. Above 815° C. both prior structures were identical in steel N.E. 9442.

From the results obtained on the higher alloyed medium carbon steels, it was found impossible to predict the hardness traverse of production parts treated from readily machinable prior

TABLE I.—COMPOSITION AND BRINELL HARDNESS OF PRIOR STRUCTURES.

Type of Steel	Composition						Brinell Hardness of Prior Structures.				
	C.	Mn.	Si.	Cr.	Ni.	Mo.	Spheroidised	Annealed	Hot-Rolled	Normalised	Oil Quenched
S.A.E. 4620	0.19	0.55	0.29	0.23	1.75	0.24	131	170	179	187	215
N.E. 9442 ..	0.43	1.15	0.45	0.25	0.30	0.11	156	170	202	255	415*
S.A.E. 4140	0.37	0.74	0.29	1.05	0.25	0.21	152	170	331	277	477*
S.A.E. 3240	0.41	0.55	0.26	1.09	1.69	0.03	182	187	302	331	578*
S.A.E. 4340	0.38	0.65	0.27	0.71	1.56	0.39	171	179	285	311	514*

* By conversion from Rockwell C.

From *Trans. Amer. Soc. for Metals*, 1944, vol. 32, pp. 521-549.

structures unless the hardenability test was conducted under reasonably equivalent conditions of time, temperature and prior structure. The advantages of long soaking times when conducted on those alloy steels from normalised, hot-rolled or quenched prior conditions, also appeared to be

over-estimated, as some of the data showed indications of a loss of hardenability under these conditions. The physical properties determined on steels S.A.E. 4140 and 4340 suggested a response to the variables considered which was parallel, but of much less extent than the hardenability variation.

Graphite Rods Applied to Open Risers

By F. J. Vosburgh and H. L. Larson

IN a previous paper¹ the authors reported on the increased yield of steel castings obtained where small graphite rods were placed in blind or semi-blind risers. Practical results were obtained which justified the tests carried out, but were only applicable to a percentage of the work done. A series of experiments were therefore started, applying the method to open risers, and in so doing a new technique was developed since the conditions of application were changed.

Before the first tests of the graphite rods started, core-sand rods had been used in open risers, being inserted at an angle through the side of the riser mould, and thereby eliminating the use of anti-piping compound on the top of the riser. As a result, the top of the riser solidified and atmospheric pressure was transmitted through the porous sand rod to the molten metal inside the solidified shell of the riser, driving the metal into the shrink of the casting. In the first experiment, graphite rods were placed horizontally in slots cut or moulded inside the riser cavity. The metal did not solidify about the ends of the rods, so that atmospheric pressure was transmitted through holes in the riser side walls and the absorption and oxidation of the graphite gave the expected benefits. As moulding the slots increased mould preparation costs, and the metal which filled the slots increased riser weight, methods of using the rod to overcome these deficiencies were investigated.

For a riser 4 in. in diameter or 4 in. wide, if rectangular, a 5 in. length rod was pointed at both ends and one end thrust into the side of the riser mould at an angle of 30°. The opposite end was then swung down to a horizontal position and the rod pulled back from the wall into which it had been thrust and pushed into the opposite wall. Another method for suspending the

rods in position in different types of open riser and suitable for round rods was developed by pointing the rod at one end and placing this end in the riser wall and preventing the end from rising with the riser metal by a nail thrust into the mould wall. Still another method consisted in using an unpointed rod supported free of the wall at both ends by nails properly located above and below the rod to prevent any movement. In both cases the shrink cavity was sealed off completely from atmospheric pressure by the solid metal.

The general conclusions drawn from the experiments were that the use of graphite rods placed across the diameter of open risers of steel castings had two distinct advantages. (a) Riser dimensions, either cross-section or height, or both, could be reduced materially, thereby reducing the necessary amount of poured metal for a casting. (b) Because of decreased cross-section of an open riser there was a material saving in cost of removing risers from castings and subsequent grinding of the castings. The same size rods were recommended for open risers as are used in general practice for blind and semi-blind risers

TABLE I

Riser, Diam. In.	Graphite Rod, Diam. In.
Up to 3	1/4
3 to 4	1/2
4 to 6	3/4
6 to 12	1

(Table I), with rod lengths 1 in. longer than riser diameters. The level of the rod within the riser should be from 2 in. to 3 in. down from the top of the cope section of the mould, depending on the length, but not on the diameter, of the riser, and the level of the rod above the riser junction with the casting should be a minimum of 2 in. to 3 in., depending on rod size, if carbon pickup in the riser must be avoided.

Graphite rods in open risers may be secured by either of the methods

described. When pointed rods were used, it was found that the riser shrink was sealed completely from contact with atmosphere or mould sand by a solidified metal shell. The internal pressure created in the sealed shrink was apparently greater than external atmosphere pressure, and consequently forced molten riser metal into the casting. The rod also appeared to be completely dissolved in the riser metal, none being oxidised because of the lack of oxygen and nothing remaining of the solid rod. The carbon pickup in the riser metal appeared to be more widely, but of no greater depth from the pointed rod, and the shrink created was wider and of less depth than results obtained from flat-ended rods.

Liquid Carburising of Transmission Gears

By W. A. Silliman

HEAVY duty tractor gears and parts must be carburised and heat-treated to unusual combinations of toughness, wear resistance and fatigue strength. The properties obtained must not only be uniform from piece to piece, but in additional distortion must be held to an absolute minimum. Parts gas carburised in batch furnaces, slowly cooled and then reheated and hardened were found to give as high as 10% rejections due to distortion. To overcome this difficulty and to keep rejections to an economically low level, such parts were treated in an electric salt bath furnace which not only solved the distortion problem but also resulted in increased production and other benefits.

The salt bath furnaces used consisted of 3 standard Ajax-Hultgen closely spaced electrode furnaces. The large furnace used had a bath working area of 72 in. × 20 in. × 24 in. and a rating of 90 kw., the small furnace of the group, a working bath area of 24 in. × 15 in. × 14 in., with an input of 35 kw., while the intermediate furnace had a bath area of 48 in. × 20 in. × 16 in. and a rating of 75 kw. The first two furnaces were installed with the idea of carburising in the larger furnace at 900° C. and stabilising the temperature at 790° C. in the smaller furnace before quenching so as to give the minimum of distortion. As it was soon proved, however, that gears directly quenched from 900° C. showed approximately the same distortion as gears which were

From *The Foundry*, 1944, vol. 72, No. 7, pp. 76-7, 180, 182, 184, 186
1 *METALLURGIA*, 1944, vol. 30, No. 176, pp. 177-178

From *Metals and Alloys*, 1944, vol. 20, No. 1, pp. 58-61.

transferred to the furnace at the lower temperature and then quenched, production was materially increased by adopting the direct quench procedure thereby placing both furnaces in production to give a maximum output.

In the salt bath method of carburising, the loading of the pots carrying the parts was staggered so that the work was charged and removed from the furnace every hour. By using such a system, a small volume of cold work is entering the furnace each hour, and the heat recovery is very rapid, with a maximum of 15 minutes on heavy parts, and the temperature drop seldom exceeds 15° C. The strength of the salt bath was maintained by predetermined additions of salt at 4 hour intervals and the bath held at a cyanide concentration of 16 to 18%. The case depth specification remained unchanged when compared with gas carburisation.

Lighter gears carry a case depth specification of 0.030 in. to 0.045 in. with about 0.038 in. to 0.040 in. as the average. With the liquid carburisation method a much closer control of depth of case can be maintained. The minimum cycle used was 7 hours, which produces a case depth of 0.050 in. minimum.

With the salt bath method of treatment and using the stagger method of loading, production can be maintained at a constant rate, whether or not there are rush items to be dealt with. Distortion is reduced to a minimum and is measured in ten-thousandths as compared to thousands by gas carburisation methods. This reduction in distortion is considered to be due to the more uniform heating of parts and more uniform quenching. In addition liquid carburisation of gears yielded a higher output rate using the same types of steel.

Variables Affecting the Results of Notch-Bar Impact Tests on Steels

By C. E. Jackson, M. A. Pugacz and F. S. McKenna

THE notched-bar impact test has proved of value in certain applications as a test for control of the quality of heat-treatment of steel. The stress system imposed on a specimen with a notch, however, is so complicated and unpredictable that no simple evaluation of the test has been possible. Variables affecting the results of notched-bar impact tests are the type and dimension of the test specimen, the testing temperature, the material being tested, the speed of test and the resistance to deformation of notched-bar specimens. Some data has been accumulated on the effects of such variables and the present investigation deals with additional data obtained as the result of a series of tests on plain carbon and low-alloy steels. The alloy steels included nickel, chromium, nickel - chromium, nickel - copper, nickel - copper molybdenum, and chromium-molybdenum steels.

All the materials were commercial hot-rolled steels, $\frac{1}{2}$ in. thick, with commercial tolerances, and were tested either in the as-rolled or in the normalized condition with specimens cut longitudinally to the direction of rolling. The majority of test specimens were standard keyhole or V-notched Charpy specimens with modifications

of breadth. An Ansler pendulum machine was used for breaking the notched bars in impact loading and all tests were run using the full energy capacity of the pendulum (200 ft.-lb.) with a striking velocity of 17.4 ft. per second.

The data obtained for different breadths of specimens, 1.2, 0.5 and 0.25 cm., with V and keyhole notches for 27 low-alloy and carbon steels were plotted, showing the effect of breadth of specimen on absorption of specific energy. The relation of decreasing energy absorption per unit area with increasing breadth was applicable only to the more brittle steels with standard notched-bar values lower than about 60 ft.-lb. In the tougher and more ductile steels, the relation of resistance to deformation and resistance to fracture was such as to give a lower specific energy absorption for the narrow specimens.

The effect of increasing the radius of the notch in similar notched bars was also determined for a number of steels. Specimens with a section 10 mm. square and a length of 55 mm. were notched to a depth of 2 mm. with a standard Charpy-type V-notch and with milling cutters of $\frac{1}{16}$ in., $\frac{1}{8}$ in., and $\frac{1}{4}$ in. radii. It was found that as the radius of the notch increased, the energy required to fracture the test

specimen was increased. The effect of type of notch and breadth of specimen on Charpy notched-bar values (temperature of test 70° F.) is shown in Fig. 1 for a series of hot-rolled plain carbon steels.

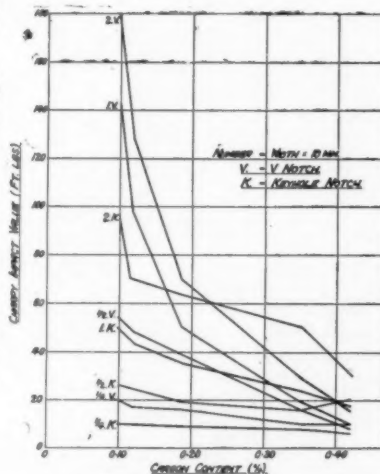


Fig. 1.—Effect of type of notch and width of specimen on Charpy impact values of a series of plain carbon steels

Curves were obtained showing the effect of testing temperature on V-notched bars of standard width, half width and double width, for a mild steel over the range 50° to 900° C. These showed that low-carbon steels were especially sensitive to the influence of low testing temperature. Two areas of increased brittleness were noted; first, the area of rapid transition from high to low energy absorption as the temperature was decreased from just above room temperature to temperatures below room temperature and second, the area of low energy absorption just below the A_1 transformation temperature. The effect of temperature of test on the results obtained for standard V-notched and keyhole specimens from a low-alloy high-tensile steel over the range 50° to 150° C. showed the increased sensitivity of the V type of notch by the steeper low-temperature drop and the wider range of values obtained.

To determine the effect of the speed of testing specimens from a number of the steels were broken in the impact machine, and a similar group were tested in a jig (identical with that of the impact machine) at a slow rate using a tensile testing machine. A stress-strain curve was made in order that the area under the curve might be measured with planimeter and

From *Metals Technology*, 1940, Vol. 11, No. 5, and *A.I.M.E. Technical Publication*, No. 1668, 17 pages.

TABLE I.—SUMMARY OF WORK-HARDENING DATA.

Steel No.	Notched Bar Impact Value ft. lb.	Type of Notch	Depth of Notch Mm.	Breadth of Specimen Cm.	Volume of Metal Surveyed Cu. in.	Average Hardness Increase %	Work Hardening α
61	4	Keyhole	5	1.0	0.141	2.0	0.28
61	4-5	Vee	2	0.5	0.048	0.8	0.04
61	21	$\frac{1}{8}$ in. radius	2	1.0	0.082	5.4	0.44
61	37	$\frac{1}{4}$ in. radius	2	1.0	0.066	14.6	0.96
61	40	$\frac{1}{2}$ in. radius	2	1.0	0.137	6.3	0.86
61	48	$\frac{3}{4}$ in. radius	2	1.0	0.129	7.5	0.97
57	5	Vee	2	1.0	0.055	2.5	0.14
57	7	Keyhole	5	0.5	0.048	8.3	0.40
57	15	Vee	2	0.5	0.068	8.0	0.54
57	15	Keyhole	5	1.0	0.096	3.8	0.36
57	15	Keyhole	5	1.0	0.112	4.8	0.54
57	20	Vee	2	1.0	0.077	5.0	0.38
57	20	Vee	2	1.0	0.107	9.2	0.98
57	29	Vee	2	2.0	0.234	1.3	0.31
57	50	Keyhole	5	2.0	0.260	3.9	0.99
57	54	$\frac{1}{8}$ in. radius	2	1.0	0.077	16.6	1.28
57	70	$\frac{1}{4}$ in. radius	2	1.0	0.139	12.3	1.71
57	95	$\frac{1}{2}$ in. radius	2	1.0	0.115	20.3	2.34
57	110	$\frac{3}{4}$ in. radius	2	1.0	0.130	20.8	2.70
57	121	$\frac{1}{2}$ in. radius	2	1.0	0.105	25.0	2.62

α —Vol. of metal surveyed (cu. in.) \times average hardness increase (Vickers Hardness Number).

converted to energy units. It was found that, in general, the energy absorption in the slow bend and in impact loading were in good agreement in homogeneous materials, but that the former showed a decided increase over the latter in a number of commercial quality non-homogeneous materials containing laminations or having fibrous breaks.

A large number of specimens were examined to observe the deformation and flow of metal in the vicinity of the notched bar fracture. A surface normal to the notch was prepared on half of each specimen and surveyed, using Vickers pyramid diamond indentations with a 10 kg. load. Indentations were made 0.05 in. apart in rows perpendicular to the length of the specimen. These rows were spaced every 0.03 in. and were staggered. The average hardness value obtained was assumed to be that of the unstrained metal. Data obtained showed that in shallow notched specimens there were

two areas, one above and one below the neutral axis, which showed a higher hardness, indicating simple beam behaviour during fracture. In the deep-notch or keyhole-notch specimens this type of deformation was not found. Fracture was caused mainly by the punching action of the nose of the pendulum hammer on the area between the nose of the hammer and the notch.

A correlation was also noted between the energy absorbed during fracture and the amount of work-hardening. The hardening values were obtained by multiplying the volume of the metal surveyed in cubic inches by the average hardness increase in Vickers hardness numbers for that area. The amount of work-hardening determined for 18 specimens of two carbon steels, containing 0.54 and 0.25% carbon respectively, with a variety of breadths and notch conditions, Table I, when plotted against the energy absorbed in foot-lbs. gave a linear relationship.

Microradiography: New Tool of Metallurgy

By S. E. Maddigan and B. B. Zimmerman

RADIOGRAPHIC examination of metals by X-rays, commonly used to detect hidden flaws, has lately been extended to reveal microstructures as well. This new tool is as yet insufficiently appreciated and merits serious consideration by metallurgists. Micrographs made of polished etched metal surfaces in the ordinary way reveal crystalline structures, and thus yield invaluable information about

the metal examined. When X-rays are transmitted through thin, polished, metal sections and then allowed to impinge on a photographic plate of extremely fine grain, the resulting radiograph can be magnified optically to reveal both microscopic flaws in the metal and the distribution of the various alloy constituents in it. When, in an application of the technique, a microradiograph of a cast alloy of 80% copper, 10% tin, and 10% lead is

compared with a photo-micrograph the dendritic growth of the metal crystals during solidification shows with exceptional clarity. This crystal structure is not revealed by a photomicrograph of the surface only. The basis of microradiography is the differential absorption of a beam of X-rays by materials having different chemical compositions. Its value depends upon selection of X-rays of wave-length adapted to the problem in hand.

The basic procedure in microradiography consists in exposing a small, special photographic film through a thin, polished specimen of the metal or alloy to be examined to a beam of X-rays of wave-lengths selected to give the best contrast. The Eastman type 548-0 spectrographic plate possesses the necessary high resolution (500 lines per mm.) to permit the developed radiograph to be magnified optically as much as 300 diameters. Radiographs thus made are subsequently enlarged by use of a metallographic microscope with transmitted light. The radiographic plate is placed on the stage of the microscope and light rays are directed through it from a source by a 45° mirror.

The absolute difference between the absorption coefficients for two materials is, in general, greater for X-rays of longer wave-length. As a result, the earlier work on microradiography was done with long wave-length X-rays, using extremely thin samples enclosed in special vacuum equipment. This was a serious deterrent to the subsequent application of the method to most metallurgical problems.

Credit for devising a practicable and relatively simple technique belongs to Clark and his collaborators, who showed that the use of characteristic X-radiations of intermediate wave-length could yield high sensitivity with greatly reduced time of exposure. Absorption coefficients of metals yield discontinuous curves when plotted against the frequencies of X-radiation. Sharp changes in this value also occur at different frequencies for different metals. Hence, it is necessary for best results to select X-ray targets of metals giving characteristic radiation of a wave-length adapted to the particular problem in hand. X-ray tubes with cobalt, copper and molybdenum targets provide radiations of satisfactory character. However, the contrast obtainable can be seriously decreased by a poor choice of operating potential. A large number of copper alloys have been investigated by this procedure.

From *The Frontier*, June, 1944.

MARSHALL RICHARDS WIRE ECONOMY



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A Rapid Laboratory Method for Estimating Basicity of Open Hearth Slag

By W. A. Philbrook, A. H. Jolly, Jr. and T. R. Henry

DETERMINATION of the basicity of open hearth slags by a new and sufficiently accurate method, which appears to be speedier than previous means, is outlined. The underlying principle is the well known fact that when burnt lime or slaked lime is shaken in water it dissolves to at least a minor degree and produces an alkaline reaction. Alkalinity can then be measured by titrating. If the reactions are quite mild, they can be determined by immersion into the solution of some type of electrode, such as the vacuum tube "glass electrode," in which the very faint electromotive force is measured through the high resistance of glass membrane.

The procedure outlined by the authors is admittedly not perfect, but no other method has yet been perfected. Error incidence was reported about the same as in other means. However, the method has the favourable aspect of eliminating human judgment factors in favour of mechanically reached conclusions, and also has the virtue of being quickly installed and operable in comparatively unskilled hands.

The method of testing starts with the spooning of slag from the furnace and pouring into a pancake mould, preferably in thin section for quick cooling. After cooling, a lump is crushed until all particles pass a 40-mesh screen. Metallic iron is removed and the powder thoroughly mixed. About 100 cm³ of water is placed in a 250 cm³ Erlenmeyer flask, to which about 200 mg. of slag powder is added by rough spoon measurement. The flask is stoppered, shaken intermittently and allowed to stand for 10 min. The pH meter is checked for customary adjustments and temperature compensation and the temperature of the slag suspension is adjusted to 75° to 80° F. (24° to 27° C.). After the glass electrode and sample cup are rinsed twice with the extract the pH reading is taken. The lime-silica ratio of the slag is obtained by reference to a correlated curve or table obtained from numerous pH measurements of analysed samples, taken under standard conditions on slags less than one day old.

It was found that as the weight of

From a paper presented at the annual meeting of the Institute of Mining and Metallurgical Engineers, Cleveland, Ohio, October, 1944.

40-mesh powder suspended in 100 cm³ of water was increased from 5 to 200 mg., the pH values increased, but beyond 200 mg. there was no gain of significance. Hence, measurement can be rough as long as it approximates a 200 mg. minimum. Virtually the full pH reading is obtainable after about 10 mins. of shaking, and further standing does not vary the result. Ordinary distilled water can be used for the work. Increasing of temperature of the solution appeared to have the effect of decreasing pH at a rate of 0.016 pH per deg. C. in a range close to 25° C. Finally, the technicians established that there was no consistent drift in pH in slags pulverised intermittently up to 10 days after pouring. This was notable, for it obviously permits the use of the process for study several days after the heats have been produced.

Smelting of Complex Tin Ores

By C. L. Mantell.

COMPLICATIONS in roasting complex Bolivian and Mexican tin ores are described. Ore dressing processes have been developed for stannite, cylindrite, franckeite and other complex ores. These processes vary considerably from the traditional and comparatively simple extraction procedures.

Four general methods are mentioned as the usual approaches to smelting processing: (1) Roasting, followed by further mechanical separation of minerals that have been physically broken away from the cassiterite as the result of the process or altered in such a manner, that is, as change in specific gravity, making them more amenable to further mechanical concentration; (2) Roasting under controlled conditions, followed by leaching with water or acid solutions; (3) Heating with sodium salts, such as soda ash, sodium chloride, salt cake, etc., followed by leaching; and (4) Metallic impurity removed by oil flotation when the impurities are present as sulphides. The three stages in the smelting of tin ores or concentrates consist of reduction, or tin smelting proper, cleaning the slags and furnace linings and recovery of tin from them, and refining the impure tin.

From The Iron Age. October, 26, 1944

New Zinc Extraction Process

ZINC is being extracted from lead blast-furnace slag by a new slag-fuming process at two U.S. smelting and refining companies. The primary product is zinc oxide contaminated with lead and other volatile constituents of slag. However, it can be processed to metallic zinc or delead to produce saleable oxide. In the process, powdered coal is introduced into the slag bath with an amount of air insufficient for complete combustion. Although reduction may be initiated by the coal, the zinc compounds are further reduced by bubbling carbon monoxide through the bath. The reaction is carried out above the boiling point of zinc. The zinc vapour oxidises upon contact with the atmosphere, is drawn off through a flue system, and collected in a baghouse. After concentrating and deleading the oxide, it can be reduced in either a retort or electrolytically. The retort has the advantage of not requiring further purification. Cadmium and lead are removed from the concentrates by sintering with salt on the Dwight-Lloyd machine. After de-dusting, the gas stream is treated in a Cottrell operated at low temperature. This method both recovers valuable cadmium and produces zinc pure enough for die-casting and other specialised uses. Germanium and indium are other valuable by-products that can be obtained from refining the oxide.

From Engineering and Mining Journal, Feb., 1944, reviewed in "Summary of Current Technological Developments," U.S. Dept. of Labour, March, 1944.

Rutile Concentration

A PUBLICATION released by the U.S. Bureau of Mines describes how high-grade rutile concentrates, for use in coating welding rods, making special alloys, and manufacturing smoke screen chemicals, are being obtained from a deposit in the state of Arkansas. Rutile is a crystallized titanium dioxide. When used for coating welding rods, it forms a protective shield during the welding process and permits metals to fuse more efficiently. High-grade rutile concentrates are prepared by the Titanium Alloy Company, of Arkansas, at its mine and mill from ore containing 3% of this mineral. By crushing and gravity separation, followed by flotation, jigging, and electrostatic and magnetic separation, a concentrate containing 95% rutile is recovered.

Information Service, Bureau of Mines, October 17, 1944.

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